STUDY OF PROCESS IMPROVEMENT TOOLS
IMPLEMENTED IN A CUSTOM ENGINEERED
MANUFACTURING ENVIRONMENT

A Thesis in
Industrial Engineering
by
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ABSTRACT

The objective of this research project is to reduce the overall lead time for the manufacture and assembly of Blow Out Preventer stacks, having a highly customized design. The research project is executed for a multi-national company, specialized in the manufacture of mechanical components in the oil and gas industry.

The work reviews some of the manufacturing strategies that are employed in today’s industries and tries to identify strategies that could be employed in a custom engineered, Make to Order environment. It then outlines some of the preliminary analysis done using the existing data from the facility. This analysis uses Six Sigma tools to develop an overview of the Blow Out Preventer production process and to identify key focus areas of the project. The preliminary analysis next focuses on the downstream final assembly process and identifies the assembly delays caused due to preassembly operations as the reason for long assembly lead time. These observations highlighted the need for a tool that could be used to plan, schedule and expedite activities at the assembly pad by taking the upstream delays into consideration.

An Assembly Delay Impact Tool (ADIT) has been created to assist in the planning and scheduling activities at the Stack Pad. This tool estimates the impact of delays on the assembly operations and hence assists in planning and expediting the upstream operations to meet the schedule. In order to develop the ADIT, assembly operations were standardized and a delay tracking tool was implemented.

Finally the ability of the ADIT to accurately simulate the assembly schedule with delays is verified. ADIT was implemented for several BOP projects at the Assembly Pad (Stack Pad) and it was found that the final delivery date with delays was predicted with mean percentage deviation of 7.63% at a 95% confidence interval.
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Chapter 1

Introduction

Companies around the world are in the process of continuously improving their profitability and generating value for their shareholders and customers. In an era of ever growing demand and diminishing resources there is increasing pressure on companies to significantly improve their resource utilization. For most manufacturing companies, operating costs are a major share of the product cost. Hence more and more companies are trying to reduce their operating costs by standardizing their manufacturing operations and eliminating wastes from their manufacturing systems. A number of manufacturing methodologies are available, that provides companies with tools to identify, track and improve key performance measures and reduce operating costs at their manufacturing facilities. Today with more companies shifting towards a custom Make to Order (MTO) / Engineer to Order (ETO) production systems, implementing existing manufacturing strategies, developed for mass production have been challenging. Hence a host of factors must be considered when selecting the proper manufacturing strategy that should be implemented at a manufacturing facility. However with the increasing complexity of the products offered and processes employed at companies, designing custom tools and strategies for manufacturing process improvements could have a greater benefit than implementing existing strategies and techniques developed for other high volume manufacturing scenarios. Having said that, one important aspect for the successful implementation of improvement activities in any organization is the support and participation of all the stakeholders involved. This includes everyone in the organization from top management to the shop floor operators. In order to generate organization-wide support for any improvement activity it is typically necessary to generate tangible productive improvements in a short period. Hence it is of utmost importance to select and implement strategies and tools that can have short term benefits as well as lead to long term manufacturing process efficiencies.
This work looks at the challenges in a custom engineered manufacturing industry. It reviews the existing manufacturing strategies used in industry and explores the possibility of implementing them in a custom engineered manufacturing environment to reduce the overall project lead time. A detailed description of the customized planning and scheduling tool capable of reducing the assembly lead time is presented. This tool has been developed with a focus on generating quick tangible results for the assembly department, leading to the future development of larger scale, high impact improvement tools.

1.1 Problem Statement

The various commonly used process and quality improvement philosophies such as Total Quality Management, Six Sigma or Lean Manufacturing all apply best to batch production manufacturing systems. All of these manufacturing concepts try to reduce the variability in the various processes. However when it comes to an industry that produces custom products using a Job Production model all these philosophies tend to fail. The main reason being that for industries such as construction, ship building etc. that operates on project to project basis significant product variability is introduced at the onset of the project. The opportunity to eliminate or reduce this variability by standardization of operations is limited due to highly customized product mix.

The primary focus of this thesis is to develop a scheduling/planning tool for the National Oilwell Varco (NOV) – West Little York Plant that could accurately predict and schedule assembly activities by taking assembly delays into consideration. NOV is a leading provider of equipment and components for the oil & gas industry. The stack pad at the NOV–West Little York plant produces Blow Out Preventer (BOP) assemblies. The major problem that NOV faces today is the low throughput and long lead times for BOP production and final assembly process. This thesis analyzes the existing processes at the NOV final assembly “Stack Pad” and proposes a model that could improve the system throughput.
1.2 Research Objectives and Methodology

The objective of this thesis is to develop a tool that could be used to reduce the lead times and improve the throughput at the NOV Stack Pad. The various process improvement tools that are currently used in industry today are first evaluated to determine the possibility of implementing these tools at NOV. Thorough analysis of the existing NOV Stack Pad operations has been performed to determine reasons for the long assembly lead times, and a tool that can be utilized to assist in assembly lead time reduction has been developed.

Chapter 2 of the thesis reviews the various process improvement tools that are currently employed in manufacturing industries and assesses the possible implementation of these tools directly at the NOV Stack Pad. Chapter 3 analyses the existing data from the Stack Pad to determine the major reasons for the current long lead times in the assembly process. Chapter 4 provides a detailed explanation of the methodology used to develop an Assembly Delay Impact tool. Chapter 4 presents a case study to verify the ability of the Assembly Delay Impact Tool to accurately simulate the Assembly schedules with delays, and to compare it to the existing methods employed at the NOV Stack Pad.

1.3 Company profile – National Oilwell Varco

National Oilwell Varco (NOV) is an American MNC headquartered in Houston, Texas which serves the oil & gas industry. NOV is a worldwide provider of components and equipment for oil and gas drilling, oilfield services, production operations and supply chain integration services. The major mechanical components supplied by NOV includes land and offshore drilling rigs, complete land drilling and well servicing rigs, tubular inspection and internal tubular coatings, drill string equipment, extensive lifting and handling equipment, and a broad offering of down hole drilling motors, bits and tools.
1.4 Spherical Blowout Preventer Stack Product Description

A blow out preventer (BOP) stack is an assembly of blow out devices which are placed at the opening of an oil well before starting the drilling operation. The BOP stack is used to prevent oil blowouts resulting from pressure buildup during the drilling operation. Generally the stack is over 15 ft. tall and weighs more than 20 metric tons. It contains highly engineered control equipment and hydraulically operated components manufactured as per the American Petroleum Institute (API) specifications.

An SBOP stack assembly is generally made of the Lower Stack and Lower Riser Marine Package (LMRP) subassemblies. A typical LMRP consists of main control console panels and an annular BOP also known as Spherical Blow Out Preventer (SBOP). While a typical Lower Stack consists of hydraulic installations, remote operated vehicles (ROV) panels and annular and ram BOPs. The design and the number of components used in a BOP stack assembly varies based on the operating standards and customer requirements (Otamendi, P.E.T., 2013).

There are two types of stacks based on design methodology adopted. The Conventional Stack, in which the parts are designed and assembled as per the customer defined specifications and the new Configurable Stack in which the customer has to select predefined part configurations from the company catalogue. The Configurable Stack has been developed as a means to reduce the long engineering and manufacturing lead time encountered as a result of the highly customized product design in a Conventional Stack.

1.5 NOV Manufacturing Systems (NOV-MS)

NOV MS is an initiative sponsored by the NOV Global Manufacturing Strategy Group, to improve NOV’s profitability and responsiveness, and to maintain its position as the leading provider of customized oil field products and services. This initiative is a collaboration between NOV, the University of Wisconsin-Madison, the
Pennsylvania State University and the Texas A&M University. The NOV plants currently participating in the NOV-MS projects are NOV-West Little York (WLY), NOV – Sam Houston Parkway (SHP), NOV – Sugarland, NOV-Galena Park and NOV FM529. The long term objective of NOV-MS is to develop, test and implement a customized Manufacturing System for the entire NOV organization. This Manufacturing System will equip the organization with the ability to be highly responsive to company, customer and market expectations of costs, lead times, quality, safety, and delivery reliability.

Some of the key challenges that lead to the creation of NOV MS initiatives are the diverse nature of the firm’s global operations, large scale impact of the upstream engineering and sourcing decisions on the downstream manufacturing operations, and the volatile product demand. NOV MS envisions overcoming these challenges by using the company’s existing knowledge of operating in a custom-engineered manufacturing environment and the universities’ knowledge of cutting edge manufacturing methodologies in a collaborative partnership.
Manufacturing industries around the world has adopted various manufacturing strategies required to meet their customer demands. These manufacturing strategies have evolved over the years. Initially craft production techniques were used, where skilled artisans and craftsmen produced products as per individual customer requirements. This method was however less responsive and resulted in higher production costs (Gunasekaran A., Ngai E.W.T., 2011). The massive demand for consumer products after World War I, required the production of standardized products in large volumes. This resulted in the development of the mass production systems. Henry Ford is considered to be one of the pioneers of the modern mass production techniques. He incorporated product standardization through interchangeability of parts and introduced the continuous assembly line (Womack J. P., Jones T.J., Roos D., 1990). Mass production helped to meet the customer’s basic product requirements, and also furthered the expectation for higher quality products at lower prices. With continuing higher competition for market share and ever declining resource availability, companies required to reduce product cost through better resource utilization and lowering operating costs. Also it became imperative that companies continuously strive to provide their customers with what they want, when they want and where they want, in order to ensure profitability (Nambiar, 2010). This has resulted in the development of various contemporary manufacturing strategies such as the Theory of Constraints (TOC), Lean Manufacturing and Quick Response Manufacturing (QRM) to help companies achieve their complex goals. Most of these and other current manufacturing strategies find their roots in the automobile industry, which is an assembly line or mass production based industry.

Most production systems in manufacturing companies are classified into make-to-order (MTO) / engineer-to-order (ETO) and make-to-stock (MTS). In MTO, both the production planning processes as well as the performance measures are order focused. The priority for MTO systems is generally shorter delivery lead time. The
main issues faced by MTO production systems are capacity planning, order acceptance and attaining high due date adherence (Soman C.A., Van Donk D.P, Gaalman G. 2002). The MTO/ETO system is characterized by production dynamics due to considerable fluctuations in terms of product mix and sales volume, uncertainty of product specification and process, and finally the complexity in quotation preparation, planning and coordination of projects and assembly structure (Bertrand J.W.M, Muntslag D.R. 1993).

Production systems at MTO companies can be further classified as High mix low volume (HMLV) or custom manufacturing. HMLV production refers to the production of a variety of products in small quantities. Custom manufacturing is similar to HMLV. However, in custom manufacturing generally the products are engineered to customer requirements, each job is linked to a specific customer order, and each has a specific completion date to be adhered to. Based on the definitions of the various production systems provided, one could classify the production system employed at NOV WLY as a custom manufacturing production system.

In MTO companies, shorter lead times provide competitive advantage. However maintaining short lead times with improved customer satisfaction is also equally important to generate future businesses. Hence quoting due dates based on the available capacity is crucial for a MTO company (Hendry C., Kingsman B.G. 1989). Several models for due date assignment are available, such as models based on constant values, models using information on arriving jobs, models using information on jobs already in the system and models using information on future jobs. Bertrand J.W.M, Muntslag D.R. (1993) has provided a framework for production control in ETO manufacturing plants. However, owing to the unique characteristics of each production environment, the production control framework must be adapted to suit these specific product family characteristics. Information sharing and physical flow coordination also help in developing an integrated supply chain, which in turn results in improved economic performance in an MTO environment (Sahin F., Robinson E.P. 2005).
Today, with more industries offering greater product variety and highly customized products, there is a growing need for manufacturing strategies that can be implemented in the Make to Order (MTO) industries. This chapter reviews some of the common manufacturing strategies used today and their feasibility in a custom engineered MTO manufacturing environment.

2.1 MRP & ERP

Material Requirements Planning (MRP) is a production planning and inventory control tool based on a push system, designed for complex production planning environments (Hopp W.J., Spearman M.L.). It was developed by Joseph Orlicky in 1964. MRP satisfies the material requirements generated from external demand by scheduling jobs and purchase orders. Manufacturing Resource Planning (MRP II), which followed the MRP system, not only coordinates the manufacturing materials but also the entire manufacturing production including demand management, forecasting, capacity planning, master production scheduling, rough-cut capacity planning, capacity requirements planning, dispatching, and input/output control.

MRP/MRP II system offers several benefits such as improved customer service, better production scheduling and reduced manufacturing costs. However MRP/MRP II systems available today are generalized tools and are not easily customized to the need of a particular industry or a company. MRP/MRP II fails to meet all the requirements of MTO companies, especially the ability to plan capacity at the customer enquiry stage (Hendry L.C., Kingsman B.G. 1989). The fundamental assumption of MRP/ MRP II system is that it is possible to forecast the demand of standard products with well-known Bill of Material (BOM) and product routings. However this assumption does not hold true in the case of MTO companies because of the high product variety and customization involved. MRP II systems do not support the distinction between standard, actual and historic BOMs. They do not establish a relation between the customer order and all of the corresponding work orders in the various departments and do not support the control of non-physical
processes such as engineering and design. Hence making MRP/MRP II systems a poor fit for MTO/ETO companies (Bertrand J.W.M, Muntslag D.R. 1993).

Enterprise Requirement Planning (ERP) is an extension of the MRP/ MRP II system. It not only incorporates the functions provided by MRP II but also addressed all the core functions of an enterprise including, accounting, maintenance and human resources. An ERP system offers benefits such as availability of real-time data, improved visibility and automation of tasks. However ERP systems also tend to be highly standardized thereby lacking the ability to support the inherently flexible and agility MTO companies (Zach O., Olsen D.H. 2011). Aslan B., Stevenson M., Hendry L.C. (2012) has identified misalignment between decision support systems provided by the ERP system and those required by MTO companies, especially at the customer enquiry and design/engineering stages. These challenges makes most ERP systems unsuitable for MTO companies. However researchers have suggested that addressing these misalignments could increase the applicability of ERP systems in the MTO sector.

2.2 Lean Manufacturing

Lean Manufacturing techniques were derived mostly from the Toyota Production System (TPS), developed by Taiichi Ohno and Shigeo Shingo for the Toyota Motor Corporation (Haque B., Moore, M.K., 2004). The term “lean production” was introduced in the book ‘The Machine That Changed the World’ published in 1990 (Holweg M., 2007). The TPS continuously evolved from its nascent stage in the late 1940’s into its modern form by the 1960’s. The oil crisis in 1973 contributed to its wide spread usage in the Japanese automotive industry. However it was after the research conducted by the International Motor Vehicle Program (IMVP) at the Massachusetts Institute of Technology and the success of the Japanese companies in US that made Western manufacturers take notice of Lean practices.
Womack J.P., Jones D.T. and Roos D. (1990) defined lean manufacturing as a 5 step process of: defining customer value, defining the value stream and eliminating waste, making the value flow, letting the customer pull the process, and pursuing perfection. According to lean philosophy anything that does not add value to the customer is considered as a manufacturing waste. Continuously keeping the organization lean through elimination of waste is central to the lean philosophy. Lean provides a plethora of tools to attain the 5 steps such as, one piece flow, Just in Time (JIT), Quick Changeover (SMED), Poka-Yoke, Jidoka, value stream mapping etc.

Although Lean finds its origin in the assembly line based automobile industry, there have been attempts to implement Lean tools in HMLV and New Product Introduction (NPI). Key elements of JIT such as production smoothing and standardization of jobs are not typically applicable to a MTO company; however, lean elements such as multifunction workers, Kanban, drive for quality and zero inventory are relevant to MTO companies (Hendry L.C., Kingsman B.G. 1989). Some of the other Lean tools such as continuous improvement, waste reduction, 5s etc. could also find application in most MTO manufacturing environments. Haque B. and Moore M.K. (2004) have identified five Lean principles that are relevant to NPI. They have shown that Lean can be applied at the localized as well as at strategic levels of NPI organizations to produce short term and long term results respectively. Stump B. and Badurdeen F. (2009) have explored the possibility of applying various manufacturing strategies at companies engaged in mass customization (MC). According to the authors most Lean principles are applicable to low-level MC where there is less customer involvement and where products are predominantly assembled-to-order. Bokhorst J.A.C., Slomp J., (2010) developed a takt time based system for a HMLV environment and defined the various phases for its implementation. It was found that under this system the amount of WIP had a strong influence on system performance measures. Hence it is important for the managers to determine the WIP level based on the process time variability encountered. In certain multi-product environments however MRP systems were found to perform better than Kanban system, especially where multiple
products were sent to assembly lines which shared assembly schedules (Krishnamurthy A., Suri R., Vernon M., 2004).

2.3 Theory of Constraints

Theory of Constraint (TOC) is a management philosophy developed by Dr. Eliyahu M. Goldratt and was presented in his book titled ‘The Goal’ (Goldratt, E.M., 1992). TOC evolved from the OPT (Optimized Production TimeTables) scheduling software into a collection of management tools, covering areas such as logistics/production, performance measurement and problem solving or thinking tools (Watson K.J., Blackstone J.H., Gardiner S.C., 2006).

TOC philosophy is based on the principle that any organization or system has a constraint or a series of small constraints associated with production which dominates the entire system. TOC states that any organization or system is limited from achieving its goal because of these constraints. The TOC process provides a 5 step approach in order to identify these constraints and to restructure the rest of the organization around these constraints (Tulasi C.H.L., Rao R.R. 2012). The 5 steps are ‘Identify’ the constraint, ‘Exploit’ the constraint, ‘Subordinate’ everything to the above decision, ‘Exploit’ the system constraint and ‘Go Back’ to step 1 to ensure continuous improvement. TOC employs a pull system upstream of the constraint resource and a push system downstream (Gupta M. 2003).

TOC is a relatively new concept; hence most of the TOC literature is focused on the improvement in the TOC concepts. Several publications related to manufacturing and project management are available, however, there has been limited work done in the area of manufacturing control in mass customization and HMLV industries. Although TOC does not offer strategies to support planning and control at the customer enquiry and job entry stages, it offers a simplified planning process due to the consideration of only the constrained resources for workload estimation (Stevenson M., Hendry L.C., Kingsman B.G. 2005). According to Stump B. and
Badurdeen F. (2009) TOC can be applied to Mass Customization companies which have a clearly identifiable and fixed bottleneck. Integrating TOC in these companies can help to improve the flexibility of their operations. Guan Z., Peng Y., Ma L., Zhang C., Li P. (2008) has proposed a combination of TOC and lean concepts to control manufacturing flow in HMLV production. They have suggested the combined use of lean techniques such as value stream mapping, flexible manufacturing cells and the TOC concept of Drum Buffer Rope (DBR). In project management, TOC offers an approach which is different from the traditional project management concepts. It proposes the use of reliability and lead time over price while selecting subcontractors. It also recommends to avoid milestones, to identify critical areas and to insert buffers wherever necessary (Goldratt, E.M., 1997). Compared to the lean approach, TOC tend to improve the responsiveness, speed and adaptability of a business. TOC was found to be a better technique over Lean, to achieve operational agility and thereby a provide a competitive advantage (Ifandoudas P., Chapman R. 2010).

2.4 Quick Response Manufacturing

Quick Response Manufacturing (QRM) is a manufacturing strategy developed in the late 1980s by Dr. Rajan Suri, a professor at the University of Wisconsin Madison. The QRM is based on the Time-based completion concept first developed by the Japanese companies in the 1980s (Tubino F., Suri R., 2000). The details of QRM are presented by Dr Suri in his book “Quick Response Manufacturing: A Companywide Approach to Reducing Lead Time”, published in 1998.

QRM is a companywide strategy which considers both the internal and external operations in order to achieve its goal of reduced lead time (Suri R, 2003). The “external operation” refers to the response to customer needs by rapidly designing and customizing products as per customer requirements. While the “internal operation” refers to the reduction of lead times of all tasks and thus ensuring lower cost, quality and quick response. The basic difference between lean and QRM is that
the main focus of QRM is the reduction of lead time, while that of lean is the reduction of waste. QRM particularly caters to companies with high product variety, companies producing highly customized products and companies where demand is highly variable (Ioing M.J., 1995). QRM provides 10 principles which debunk some very common manufacturing practices and reinforce the understanding of manufacturing dynamics. QRM also provides various analysis techniques and tools such as POLCA “Power of Six” rule and QRM cells to achieve objectives.

Krishnamurthy A. and Suri R. (2009) has proposed Paired-cell Overlapping Loops of Cards with Authorization (POLCA), a hybrid push/pull material control strategy, for companies with high variety or custom engineered products. According to them POLCA is a better alternative than Kanban in a high variety or custom engineered product environment. Actual cost benefits of reduced lead times achieved through implementation of QRM cannot be full realized by traditional accounting methods, hence a rule of thumb called “Power of Six” is used as a performance measure in QRM (Tubino F., Suri R., 2000).

This literature has reviewed the various manufacturing strategies that are used in industry today. Although strategies such as Lean and TOC cannot be directly implemented in an MTO environment, they offer tools that could be customized and incorporated to suit the needs of a specific company. Of all the strategies researched here QRM seems to offer a system which could find direct application in a MTO company. However QRM is a relatively new concept and requires further refinement before it could be recommended as a tool that could be adopted at NOV. In general, this review of the literature suggests that there is an absence of a “one size fit all” strategy that could be implemented at MTO companies, and hence the need to develop customized tools as per the specific production requirements for MTO companies. Therefore in this study a customized tool was developed to help reduce assembly lead time for SBOP stacks at NOV, whose details are covered in the following chapters.
Chapter 3
Preliminary Analysis

The objective of this research project is to reduce the production and assembly lead time of a Stack Assembly. The Stack Assemblies are custom engineered as per the specifications provided by the customers. Hence one of the biggest challenges faced by NOV is the inability to standardize the manufacturing and assembly operations in this custom engineered environment. The first step in the research project was the identification of different processes and stakeholders involved during the life cycle of a Stack project, and then to focus on the critical issues, in order to achieve the research project objectives.

This chapter also discusses preliminary analyses that were conducted as part of the earlier stages of the NOV MS Stack Assembly research project (Otamendi, P.E.T., 2013).

3.1 Methodology
As mentioned earlier, the complexity of Stack Assembly improvement lies primarily in the lack of process standardization, which is a challenge to all custom engineered manufacturing environments. However there are a host of other reasons which add to Stack Assembly complexity. A typical BOP Stack project from sales to final assembly takes approximately two years. A number of different departments are involved in the Stack manufacturing process. The successful execution of any Stack project requires a well-coordinated effort from many departments over an extended period of time before the start of final assembly. The number of people involved and the unique set of formal and informal communication tools currently used by these departments adds to the complexity of the stack projects. The internal and external supply chain also plays a very major role in ensuring that quality components are delivered on time. The final stack includes many long lead time components and subassemblies whose on time delivery depends on various internal and external
factors. Hence a well-synchronized effort between project management, supply chain and the final assembly department is necessary to avoid delays and rework at final assembly.

Therefore after evaluating the overall scope of the project through discussions with the stake holders and also considering the complexities involved, it was decided that the initial focus of the project should be towards developing a high level assembly analysis. This high level analysis was geared to clearly establish the overall pre assembly (upstream) and assembly (downstream) process which could be later used to conduct a more detailed analysis of the upstream and downstream operations. This high level analysis would also provide a holistic view of the stack build and assembly process. Compared to a localized, departmental focused approach, a holistic view would allow the identification and resolution of component delays that would have a larger impact on the on-time stack deliveries. Data for this analysis was obtained from various sources including data from the NOV ERP system and data developed from interviews with key NOV stake-holders etc. The various high level analysis and the conclusions drawn from them are discussed below.

3.1.1 **Information Flow Network**

An ideal and actual information flow network was created to identify the assembly and information flow for a typical BOP Stack project, Figure1 & 2. This network was developed through a vetting process with key members of the various departments.
This analysis helped to identify the key departmental interactions and potential causes of delays in every department. This analysis also revealed the lack of historical data to support further analysis required to realize the research project objectives. Hence the team developed a qualitative data structure through general surveys and interviews with key personnel.
3.1.2 Interaction Diagram

Having identified the information flow between departments, the next logical step was to identify the roles and responsibilities of the individual departments and the influence that departmental processes had on the overall Stack project lead time. Surveys and interview were used to collect data for this analysis. The survey included general questions used to identify the decision drivers and the “delay generators” in every department.

All the departments including, sales, design engineering, project management, supply chain, manufacturing engineering, assembly and quality assurance, were part of this survey. In order to understand the specific delay issues determined from the survey and to identify the personnel responsible for addressing delays, a customized interview was designed. The interview questions were designed such that they would help to clarify the responses obtained from the survey. These questions also assisted in determining the roles and responsibilities of the key personnel in ensuring on-time project execution.

An Interaction diagram was created using the responses from the surveys and questionnaires, Figure 3. This diagram captured information flow between departments, and the causes of potential delays in the departments. The interaction diagram provided a summary of the type of delays, source of these delays and the departments to which the complaints regarding the delays were directed.
An important observation from the Interaction Diagram was that the majority of the complaints regarding delays were directed to the engineering department. Since most of the downstream processes depend on design deliverables from the engineering department, it could be concluded from the Interaction Diagram that engineering delays are a major cause of the BOP Stack project delays.

Two recommendation tables comprising of information and internal process improvement recommendations along with a corresponding fishbone diagram were also created along with the Interaction Diagram, Figure 4 & 5. The purpose was to consolidate the key suggestions for process improvements made by every department and then to communicate those process improvement opportunities, to the responsible department.
Figure 4: Suggestions for communication improvements for the various departments (colors indicate the department origin of comments using the same color scheme). (Otamendi, P.E.T., 2013)

- Improve customer communication knowing specifics with sufficient time
- Create timelines adjusted to reality after engineering definitions
- Use of ECR
- Improve communication with vendors through coded documents
- Improve communication with supply chain to build up “safe to stock” items
- Done 120 days prior to stack kit complete
- Communicate late deliveries promptly
- Key personnel retention in the organization
- Use of ECR
- Improve E BOM revisions with Engineering
- Eliminate unnecessary NCRs and revise NCR proc.

Figure 5: Fishbone Diagram explaining the root causes for delays and late delivery of stacks from the pre-assembly to the assembly processes. (Otamendi, P.E.T., 2013)

Use of these tools helped to qualitatively identify the bottlenecks at the various departments which were the focus of future more detailed analysis.
3.1.3** SIPOC (Supplier, Input, Process, Output, Customer)**

A SIPOC analysis was used to summarize the results obtained from the interviews, surveys, information flow network, interaction diagram and fishbone diagrams. SIPOC charts were created for every department, taking into consideration the complexity of the Stack Assembly process, Figure 6. The SIPOC along with the earlier analyses were used to prepare detailed Process Flow maps.

![Assembly SIPOC chart](image)

**Figure 6: Example SIPOC chart for the Assembly department. (Otamendi, P.E.T., 2013)**

3.1.4** Process Flow Maps**

Process flow maps for each department were created to supplement the findings of the interaction diagram Figure 7. They were developed in order to consolidate the findings of the Interaction Diagram and to simultaneously present the effects of the process constraints in the upstream preassembly process and the effect on the downstream assembly process.
Figure 7: BOP stack information process flow for pre-assembly processes (Otamendi, P.E.T., 2013)
3.2 Downstream Analysis

Based on the results of the interviews, surveys, SIPOCs, Process Flow Maps and at the same time considering the complexity of the Stack Assembly project, it was decided to perform two separate analyses. The first analysis focused on the upstream, pre-assembly activities comprising of sales, project management, engineering and supply chain while the second analysis focused on the downstream activities, comprising of NOV component manufacturing and the final assembly process. The upstream side analysis was led by the Wisconsin Madison NOVMS team and the downstream side analysis by the Penn State NOVMS team.

The focus of the downstream analysis was towards improving the efficiency of the assembly processes. A series of analyses were done to determine the assembly process improvement opportunities. Most of the analyses were conducted using the existing data for the old SBOP stack design (conventional stack). The data for the analyses were obtained from the NOV ERP system (Glovia and Kronos).

The first step in the downstream analysis was the evaluation of total assembly hours using the login data available from the ERP system. The list of assembly operations and operation duration obtained from the system were compared against standard assembly operation duration. Here it was observed that the sequential operation numbers of individual projects did not match for the different stack assemblies, thereby making it difficult to compare two assembly sequences at the operational level. This also made the use of conventional SBOP data for studying the new configurable stack design very challenging. Therefore these analyses were conducted at an overall stack assembly level rather than at an operational level so as to have a common frame of reference.

All of the downstream analyses were geared towards developing a standard and improving the stack assembly process for the new configurable stack design.
However due to the lack of sufficient historical data for the configurable stack assembly; data from the older conventional stack were also used for the analysis. For the purpose of the downstream analysis, data from three projects using conventional stack (1.1, 1.2, 1.3) and four projects using configurable stack (2.1, 2.2, 2.3, 2.4) were used.

3.2.1 Information System

Data required for the downstream analysis of the operations at the stack pad assembly was obtained primarily from two NOV ERP systems Glovia and Kronos. Glovia is the ERP business management system, while Kronos is a work force management tool used at the NOV West Little York Plant.

3.2.1.1 Kronos

Kronos monitored and recorded the log in and log out information of all employees. The records were created with reference to specific operations as per the assembly router of a particular assembly project.

3.2.1.2 Glovia

Glovia recorded and managed data for the different business functions at NOV including sales, product design, procurement, post sales service and customer service. This system is used to manage information flow between the different departments and businesses at NOV and at the same time track information from both suppliers and customers. Glovia was also capable of extracting information from other NOV information systems including Kronos.

3.2.2 Data Collection

Reports from Glovia were downloaded in the form of a spreadsheet. The spreadsheet contained information regarding Work Order number (WO), cost centers, man hours, operators, machine numbers, dates, routing numbers etc. The reports were downloaded using specific filters. For example specifying a particular WO as the filter would generate a report containing information regarding cost centers, man hours, operators, machine numbers, dates, routing numbers etc. for that particular WO. The reports for the downstream analysis were retrieved from Glovia using WO
as the filter. Information such as transaction dates, run hours, cost center, routing operations and employee information were retrieved for the downstream analysis.

Every Stack Pad assembly project had three separate Work Orders: Lower Riser Marine Package (LMRP) assembly, Lower Stack (LWR STK) assembly and final Testing and Tear Down (TTD). Each Work Order data set generally included all the assembly operations related to that specific Work Order. The Work Order for the LMRP contained all of the assembly, subassembly and quality control (QC) operations related to the final assembly of LMRP. The Work Order for LWR STK included all of the assembly, subassembly and quality control (QC) operations related to the final assembly of LWR STK. The Work Order for TTD consists of operations for the final testing and tear down and preparation for delivery to the port. For the purpose of the downstream analysis, all QC operations related to LMRP and LWR STK have been excluded from analysis because QC times and direct labor hours are not recorded. Also the re-assembly operations at the port related to the TTD has also been excluded from the analysis.

3.2.3 Assembly Resource Constraint Analysis

The Assembly Resource Constraint analysis was conducted to study the manpower utilization for each project at the stack pad assembly. The data from the LMRP, LWR STCK and TTD of each project was combined and presented in the form of a histogram, Figure 8. Both the conventional as well as the configurable stacks were included in the analysis, with a separate histogram created for each project. The reasons for the assembly man hour trends observed from the analysis were determined through a formal vetting process with NOV personnel.
Figure 8: Example of Assembly Resource Constraint Analysis (conventional stack). (Otamendi, P.E.T., 2013)

One general observation from the histogram was the presence of days where the manpower utilization was 0%. This 0% utilization was observed even after excluding weekends and other non-working days. The potential reasons for these assembly delays would have been either delays due to the non-availability of assembly parts, last minute engineering changes, shifting of workforce to other higher priority projects on the stack pad, or due to a combination of one or more of these reasons.

Another observation was the longer assembly time for Configurable Project 2.1 even though the total hours consumed for the project was similar to that of the other conventional stacks. 2.1 was the first configurable stack assembly being executed at the stack pad. New designs and procedures were being implemented for the first time and hence the long assembly time could be attributed to the delay in receiving the new assembly components and to the inexperience of the workforce assembling the new configurable design. It was also observed that in some cases the assembly time was higher due to the use of mock up parts. The mock up parts were used as a temporary substitute for a late arriving actual component, so that other downstream assembly operations could be completed. However it was noted that use of mock up parts resulted in future delays due to the additional time spend in tearing down and reassembling the BOP stack once the actual components arrived.
3.2.4 **Resource Utilization Analysis**

The Assembly Resource Constraint analysis considered one assembly project at a time; however it was also necessary to study the overall resource utilization for the entire seven stack pads. Hence the Resource Utilization analysis was conducted to study the manpower utilization of the entire stack pad assembly, for all assembly projects over a given time period. A time period of 18 months, spanning from June 4th 2011 to December 15th 2012 was considered for the analysis, Figure 9. Another Resource Utilization analysis was done for a time period of 7 months, spanning from May 5th 2012 to December 15th 2012, including only the configurable stack projects, Figure 10. This was done to compare the labor utilization for the conventional and configurable stack assembly projects.
3.2.5 Assembly Sequence Analysis

The Assembly Sequence Analysis was conducted to study the idle/wait time between operations for an assembly project and to check for the occurrence of similar assembly delay patterns across different projects, Figure 11. The Assembly sequence was created in the form of a Gantt Chart. It was created using the operation sequence available from...
the routing sheet and from the operation hours and operation execution dates retrieved from Glovia. This analysis helped to identify the presence of idle/wait time in between the assembly operations. It also showed the inconsistencies between the operation sequences among different projects. The root causes of the idle times were determined through a vetting process with the assembly staff. From the vetting process the upstream processes, resulting in late component delivery, were found to be the major cause of delays.

Figure 11: Example of Assembly sequence for the LMRP for a general configurable stack project. (Otamendi, P.E.T., 2013)
3.2.6 **Ideal Assembly Analysis**

 Having identified the presence of idle/wait time during project execution, an Ideal Assembly scenario without idle/wait time was developed. This analysis was done to identify the throughput capacity of the stack pad assembly and develop a benchmark for future projects.

Initially, total assembly man hours required for the 4 available configurable stacks were studied. It was found that the minimum assembly times for LMRP, LWR STK and TTD among these 4 projects where less than the estimated standard achievable time, Table 1. This showed that a stack assembly completion time less than the estimated standard achievable time is possible under ideal conditions. The study of the minimum achievable time was then extended to the operation level for the 4 configurable projects yielding similar results, Figures 12 & 13. Hence based on these results, the minimum achievable project completion times from recent studies were used instead of the standard achievable time for the construction of the Ideal Assembly analysis.

<table>
<thead>
<tr>
<th>Projects</th>
<th>LMRP (hrs)</th>
<th>LWR STK (hrs)</th>
<th>TTD (hrs)</th>
<th>TOTAL (hrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.1</td>
<td>2,083</td>
<td>7,421</td>
<td>2,083</td>
<td>11,587</td>
</tr>
<tr>
<td>2.2</td>
<td>2,981</td>
<td>7,065</td>
<td>2,677</td>
<td>12,723</td>
</tr>
<tr>
<td>2.3</td>
<td>3,183</td>
<td>7,297</td>
<td>1,916</td>
<td>12,396</td>
</tr>
<tr>
<td>2.4</td>
<td>2,681</td>
<td>5,340</td>
<td>3,706</td>
<td>11,726</td>
</tr>
<tr>
<td>STD times</td>
<td>2,284</td>
<td>3,482</td>
<td>2,200</td>
<td>7,966</td>
</tr>
<tr>
<td>Minimum achievable to date</td>
<td>1,746</td>
<td>3,440</td>
<td>1,916</td>
<td>7,102</td>
</tr>
</tbody>
</table>

*Table 1: Estimated cycle time (hrs.) summary for each configurable stack project. (Otamendi, P.E.T., 2013)*
Four analysis scenarios were considered for the Ideal Assembly analyses:

i. Scenario 1 – Current labor status of the stack pad assuming minimum achievable operational times with current available and applied man hours

ii. Scenario 2 – Current best case scenario with dedicated workforce for each project

iii. Scenario 3 – Current best case scenario without labor constraints
iv. Scenario 4 – A no delay ideal assembly sequence that does not take into account any of the labor constraints for a typical ideal assembly under the critical path for the first configurable stack project

3.2.6.1 **Scenario 1 – Currently available and applied man hours**

In this scenario the cycle time of the stack pad was determined considering the current labor status (70% labor utilization) and minimum achievable operation hours. The weekly available man-hours at the Stack Pad assembly (5 pads) were obtained from Glovia. This was converted to weekly applied man hours for a single pad considering the current labor utilization rate of 70%. The minimum achievable project completion time determined earlier was divided by the weekly applied man-hours to determine the cycle time of the stack pad. The cycle time calculation was further extended for labor utilization rates greater than 70% and for 4 to 7 total assembly stack pad pads. The results obtained are shown in Tables 2 & 3.

<table>
<thead>
<tr>
<th>Labor Resource Utilization</th>
<th>Cycle time for Assembly Time (weeks)</th>
<th>Cycle time for Total Assembly Time (weeks)</th>
<th>Single pad throughput (stacks/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>8.3</td>
<td>11.4</td>
<td>4.6</td>
</tr>
<tr>
<td>80%</td>
<td>7.1</td>
<td>10.1</td>
<td>5.1</td>
</tr>
<tr>
<td>90%</td>
<td>6.5</td>
<td>9.6</td>
<td>5.4</td>
</tr>
<tr>
<td>100%</td>
<td>5.9</td>
<td>9.0</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Table 2: Cycle time and throughput per pad for different labor utilizations (Scenario 1). (Otamendi, P.E.T., 2013)

<table>
<thead>
<tr>
<th>Labor Utilization</th>
<th>Throughput comparison with increase of capacity (stacks/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One pad</td>
</tr>
<tr>
<td>70%</td>
<td>4.6</td>
</tr>
<tr>
<td>80%</td>
<td>5.1</td>
</tr>
<tr>
<td>90%</td>
<td>5.4</td>
</tr>
<tr>
<td>100%</td>
<td>5.8</td>
</tr>
</tbody>
</table>

Table 3: Comparison between current capacity and estimated increase in capacity at the stack pad for scenario 1. (Otamendi, P.E.T., 2013)

From scenario 1 it was found that, at the current utilization rate of 70%, while using the planned capacity of 7 pads, a throughput of 32 stacks per year are achievable. It was also observed that by increasing the labor utilization rate by 10%, to an overall labor utilization of 80%, a throughput of 36 stacks/year can be achieved.
3.2.6.2 Scenario 2 – Dedicated workforce for each project

In this scenario the cycle time of the stack pad was determined considering a dedicated stack pad workforce of 6 members. Under this assumption the work force assigned to a pad will only work for the specific project and will not be shifted to other projects as in scenario 1. The workforce crew size of 6 members was used based on the discussion with the assembly supervisors.

The weekly available man-hours for a single pad were determined for the 6 member crew and this was converted to weekly applied man hours considering the current labor utilization rate of 70%. The minimum achievable LMRP and LWR STK completion time was divided by the weekly applied man-hours and 2 weeks of standard cycle time for TTD was added to estimate the cycle time of the stack pad. The cycle time estimations were further extended for labor utilization rate greater than 70% and for 4 to 7 pads. The results obtained are provided in Tables 4 & 5.

<table>
<thead>
<tr>
<th>Labor Resource Utilization</th>
<th>Hrs/week</th>
<th>Cycle Time for Assembly Time (weeks)</th>
<th>Cycle Time for Total Assembly Time (weeks)</th>
<th>Single pad throughput (stacks/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>504</td>
<td>10.3</td>
<td>12.3</td>
<td>4.2</td>
</tr>
<tr>
<td>80%</td>
<td>576</td>
<td>9.0</td>
<td>11.0</td>
<td>4.7</td>
</tr>
<tr>
<td>90%</td>
<td>648</td>
<td>8.0</td>
<td>10.0</td>
<td>5.2</td>
</tr>
<tr>
<td>100%</td>
<td>720</td>
<td>7.2</td>
<td>9.2</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Table 4: Cycle times under Scenario 2 at various workforce utilization levels. (Otamendi, P.E.T., 2013)

<table>
<thead>
<tr>
<th>Labor Utilization</th>
<th>One pad</th>
<th>Throughput comparison with increase of capacity (stacks/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>4.2</td>
<td>16.9, 21.1, 25.4, 29.6</td>
</tr>
<tr>
<td>80%</td>
<td>4.7</td>
<td>18.9, 23.6, 28.4, 33.1</td>
</tr>
<tr>
<td>90%</td>
<td>5.2</td>
<td>20.8, 26.0, 31.2, 36.4</td>
</tr>
<tr>
<td>100%</td>
<td>5.7</td>
<td>22.6, 28.3, 33.9, 39.6</td>
</tr>
</tbody>
</table>

Table 5: Comparison between current capacity and estimated increase in capacity at the stack pad for scenario 2. (Otamendi, P.E.T., 2013)

Scenario 2 was developed to show the impact of having a dedicated work force on each assembly pad. In scenario 2 it was found that, at the current utilization rate of 70%, while using the planned capacity of 7 assembly pads, a throughput of 30
stacks/year are possible. This is less than what could be achieved under the same assumptions for scenario 1.

3.2.6.3 Scenario 3 – “Current best case scenario without labor constraints”

In this scenario the cycle time for stack pad was estimated considering the full availability of the assembly workforce at all the assembly pads. A crew of 9 people on an average was considered for this scenario. The crew size of 9 is an average value and could increase or decrease among different projects due to shifting of crew based on project assembly priorities.

The weekly available man hours for a single pad were determined for the average crew size of 9 and this was converted to weekly applied man hours, considering the current labor utilization rate of 70%. The minimum achievable LMRP and LWR STK completion time was divided by the weekly applied man hours as in previous cases and 2 weeks of standard cycle time for TTD was added to determine the total cycle time of the stack pad, similar to scenario 2. The cycle time calculation was further extended for labor utilization rates greater than 70% and for 4 to 7 pads. The results obtained are provided in Tables 6 & 7.

<table>
<thead>
<tr>
<th>Labor Resource Utilization</th>
<th>Hrs/week</th>
<th>Cycle Time for Assembly Time (weeks)</th>
<th>Cycle Time for Total Assembly Time (weeks)</th>
<th>Single pad throughput (stacks/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>70%</td>
<td>720</td>
<td>7.2</td>
<td>9.2</td>
<td>5.7</td>
</tr>
<tr>
<td>80%</td>
<td>823</td>
<td>6.3</td>
<td>8.3</td>
<td>6.3</td>
</tr>
<tr>
<td>90%</td>
<td>926</td>
<td>5.6</td>
<td>7.6</td>
<td>6.8</td>
</tr>
<tr>
<td>100%</td>
<td>1029</td>
<td>5.0</td>
<td>7.0</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Table 6: Cycle times under Scenario 3 at various workforce utilization levels. (Otamendi, P.E.T., 2013)

<table>
<thead>
<tr>
<th>Labor Utilization</th>
<th>Throughput comparison with increase of capacity (stacks/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>One pad</td>
</tr>
<tr>
<td>70%</td>
<td>5.7</td>
</tr>
<tr>
<td>80%</td>
<td>6.3</td>
</tr>
<tr>
<td>90%</td>
<td>6.8</td>
</tr>
<tr>
<td>100%</td>
<td>7.4</td>
</tr>
</tbody>
</table>

Table 7: Comparison between current capacity and estimated increase in capacity at the stack pad for scenario 3. (Otamendi, P.E.T., 2013)
In scenario 3 it was found that, at the current utilization rate of 70%, using full pad availability (7 pads), a 20% throughput increase could be obtained when compared to scenario 2.

3.2.6.4 **Scenario 4 – No delay ideal assembly sequence**

In this scenario a no delay assembly sequence is considered. The precedence constraints of the operations for building the assembly sequence were obtained through the vetting process. Man hours per day were considered to be the same as that of current available hours with an average crew size of 6. The crew size required to achieve the required labor utilization goals and throughput was determined and is shown in Table 8.

<table>
<thead>
<tr>
<th>Touch time</th>
<th>Available hrs</th>
<th>Average crew</th>
<th>Days of completion</th>
<th>Utilization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1,772</td>
<td>2,531</td>
<td>6</td>
<td>21</td>
<td>70%</td>
</tr>
<tr>
<td>1,772</td>
<td>2,531</td>
<td>4</td>
<td>32</td>
<td>70%</td>
</tr>
<tr>
<td>1,772</td>
<td>3,840</td>
<td>6</td>
<td>32</td>
<td>46%</td>
</tr>
</tbody>
</table>

*Table 8: Required crew size to achieve desired labor utilization goals and throughput. (Otamendi, P.E.T., 2013)*

It was found that a crew size of 4 could ensure project completion with 70% utilization rate and same number of available man hours as that of a 6 member crew. This reduction in crew size will ensure cost savings in terms of reduced work force however it would increase the cycle time to 32 days as compared to 21 days for a 6 member crew.

3.2.6.5 **Observations**

The company currently uses 5 pads for stack assembly at a labor utilization of 70%. However the company plans to expand its capacity to 7 pads which would help increase the throughput. A summary of analysis done using Scenario 1, 2 & 3, for 6 pads has been provided in Table 9, 10 & 11. From the tables it is evident that with the current labor utilization rate of 70% the throughput target of 24 stacks is achievable under all scenarios. It also shows that increasing the labor utilization rate to 85% and
finally 100% could further improve the throughput. Therefore throughput could be increased by adding capacity in the form of labor or by completely utilizing the 7 available pads. However the best alternative would be the complete utilization of the existing pads without adding further labor.

<table>
<thead>
<tr>
<th>Assembly pad throughput (70% Utilization)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Total (wks/stack)</td>
</tr>
<tr>
<td>11.4</td>
</tr>
<tr>
<td>Per pad (stacks/year)</td>
</tr>
<tr>
<td>4.6</td>
</tr>
<tr>
<td>Total throughput for 6 pad capacity (stacks/year)</td>
</tr>
<tr>
<td>18</td>
</tr>
</tbody>
</table>

Table 9: Assembly pad throughput analysis under the three scenarios with 70% labor utilization. (Otamendi, P.E.T., 2013)

<table>
<thead>
<tr>
<th>Assembly pad throughput (100% Utilization)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Total (wks/stack)</td>
</tr>
<tr>
<td>9.0</td>
</tr>
<tr>
<td>Per pad (stacks/year)</td>
</tr>
<tr>
<td>5.8</td>
</tr>
<tr>
<td>Total throughput for 6 pad capacity (stacks/year)</td>
</tr>
<tr>
<td>35</td>
</tr>
</tbody>
</table>

Table 10: Assembly pad throughput analysis under the three scenarios with 100% labor utilization. (Otamendi, P.E.T., 2013)

<table>
<thead>
<tr>
<th>Assembly pad throughput (85% Utilization)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scenarios</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>Total (wks/stack)</td>
</tr>
<tr>
<td>9.8</td>
</tr>
<tr>
<td>Per pad (stacks/year)</td>
</tr>
<tr>
<td>5.3</td>
</tr>
<tr>
<td>Total throughput for 6 pad capacity (stacks/year)</td>
</tr>
<tr>
<td>21</td>
</tr>
</tbody>
</table>

Table 11: Assembly pad throughput analysis under the three scenarios with 85% labor utilization. (Otamendi, P.E.T., 2013)

Hence from this analysis it is evident that the capacity of NOV WLY facility is sufficient to achieve the throughput targets. However this analysis assumes an ideal,
no delay assembly. Therefore in order to meet the throughput targets without adding capacity it is necessary to eliminate or reduce the delays in the assembly process.

3.3 Conclusion

The preliminary analysis was conducted to understand the Stack Pad Assembly process in detail and to determine the key NOV departments and stakeholders. The preliminary analysis used historical data to identify problem areas. This helped to redefine the NOVMS project scope and to focus on two areas; that is the upstream preassembly process and the downstream assembly process. The analysis conducted at the downstream side helped to identify delays from the upstream side as the major cause for the long assembly lead times. The Ideal Assembly analysis scenarios also showed that, for an ideal assembly with no delays, using existing labor utilization rates and the use of 6 or 7 pads, would be sufficient to meet NOV’s throughput target of 24 assembly projects a year. These results confirmed the need to implement tools and practices at NOV WLY facility, which could reduce the assembly delays.
Chapter 4

Assembly Delay Impact tool

From the preliminary analysis completed and presented in Chapter 2, it could be concluded that the primary reasons for long sub-sea stack assembly lead time are, the upstream delays and waiting for late components and subsystems. It was also observed from an operation flow analysis that the operation sequence, operation IDs, assembly hours and the number of operators were not standardized across all the configurable stacks.

In this chapter initially a brief explanation of the various analysis and vetting processes conducted to develop a standardized assembly process are discussed. Based on the findings drawn from these analyses, an Assembly Delay Impact Tool (ADIT) was created. The remainder of the chapter provides a detailed description of the methodology used for the creation of the ADIT.

4.1 Data Collection

The focus of the analysis in this chapter is to develop a new standardized assembly procedure, which could be used for any configurable stack at the stack assembly pad. One of the biggest challenges in achieving this was the lack of useful production and process data. The existing data collected from NOV Kronos and Glovia management systems was found to be insufficient. Based on the initial analysis using this data, it was found that the operation IDs and descriptions were not similar across different assembly projects. Therefore the standard hours for assembly operations and the proper sequence of assembly operations could not be determined using historical data.

One of the most important concepts in developing a Lean production operation is workforce participation in process improvement activities. Having found that the historical data was inadequate for the analysis, it was decided to use the knowledge
and experience of the stack pad workforce for assembly process standardization. The data for further analysis was developed through a formal vetting process with the NOV WLY Stack Pad manager and supervisors (Pizano, C., 2013).

4.2 Methodology

Following section provides the detailed description of the methodologies adopted for the various analyses leading up to the creation of the Assembly Delay Impact Tool.

4.2.1 Standard Assembly Sequence

One of the challenges of developing a standardized assembly procedure for a custom engineered product is the dissimilarity in the components used and the assembly process of individual projects. Initially the set of operations pertaining to the assembly of a specific configurable stack assembly project was developed. Next, the operations in the assembly procedure which are common for all of the configurable stacks were identified. Having identified the common operations, the remaining operation descriptions were developed considering all of the assembly alternatives possible, based on the configurable stack projects executed thus far. Hence a standardized assembly procedure was developed which clearly defined the common operations and at the same time considered all the scenarios that could arise in case of specialized sub-operations (Pizano, C., 2013).

Standardization of parameters such as operation number, precedence constraints, standard operation time and the number of operators required per operation were evaluated and standardized during the vetting process. The assembly process data generated as part of this vetting process is shown in Table 12, 13 & 14, for the three major assembly subsystems: the “Lower Stack”, the “LMRP”, and final testing and tear down. Many but not all LMRP assembly operations can be done in parallel with Lower Stack assembly operations. The Lower Stack and the LMRP must be assembled together prior to final testing and tear down.
<table>
<thead>
<tr>
<th>ID</th>
<th>OP #</th>
<th>Task Name</th>
<th>Predecessors</th>
<th>Standard Assembly Duration</th>
<th>Standard Assembly Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>200</td>
<td>TEST STUMP, LWR SPIDER, LWR BOP</td>
<td></td>
<td>0.5 days</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>LWR BOP DUAL VALVES</td>
<td>3</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>400</td>
<td>LOWER MINI SPIDER, UPPER BOP</td>
<td>3</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>500</td>
<td>UPPER BOP DUAL VALVES</td>
<td>8</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>13</td>
<td>600</td>
<td>UPR MINI SPIDER, SPACER SPOOL/SINGLE BOP</td>
<td>13</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>17</td>
<td>700</td>
<td>UPPER SPIDER</td>
<td>17</td>
<td>0.63 days</td>
<td>60</td>
</tr>
<tr>
<td>28</td>
<td>800</td>
<td>4 LEGS</td>
<td>17</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>37</td>
<td>900</td>
<td>ATTACH MINI SPIDER TO LEGS</td>
<td>28</td>
<td>0.55 days</td>
<td>40</td>
</tr>
<tr>
<td>44</td>
<td>1000</td>
<td>DCB BOTTLES AND PISTON BOTTLES</td>
<td>37</td>
<td>30 hrs</td>
<td>120</td>
</tr>
<tr>
<td>45</td>
<td>1100</td>
<td>HYDROPHONIC PODS AND ARMS</td>
<td>37</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>46</td>
<td>1200</td>
<td>BARRIER BOTTLE RACKS</td>
<td>37</td>
<td>26.7 hrs</td>
<td>80</td>
</tr>
<tr>
<td>47</td>
<td>1300</td>
<td>FIT ACOUSTIC POD</td>
<td>3</td>
<td>2 hrs</td>
<td>4</td>
</tr>
<tr>
<td>48</td>
<td>1400</td>
<td>INSTALL TRAP DOOR AND LADDER</td>
<td>37</td>
<td>20 hrs</td>
<td>40</td>
</tr>
<tr>
<td>49</td>
<td>1500</td>
<td>INSTALL ACOUSTIC POD 1st TIME</td>
<td>47,48</td>
<td>1.3 hrs</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>1600</td>
<td>FABRICATE SHUTTLE VALVE TREES (LWR STK)</td>
<td></td>
<td>35 hrs</td>
<td>140</td>
</tr>
<tr>
<td>51</td>
<td>1700</td>
<td>INSTALL SHUTTLE VALVE TREES AND SPMS</td>
<td>37,50</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>52</td>
<td>1800</td>
<td>FIT AND INSTALL EHBS POD</td>
<td>37</td>
<td>2 hrs</td>
<td>4</td>
</tr>
<tr>
<td>53</td>
<td>1900</td>
<td>INSTALL ROV PANELS</td>
<td>37</td>
<td>2.5 days</td>
<td>180</td>
</tr>
<tr>
<td>67</td>
<td>2000</td>
<td>CUT PIPE</td>
<td></td>
<td>100 hrs</td>
<td>100</td>
</tr>
<tr>
<td>68</td>
<td>2100</td>
<td>FIT/TACK SS PIPING</td>
<td>49,51,52,53,67</td>
<td>4.17 days</td>
<td>400</td>
</tr>
<tr>
<td>78</td>
<td>2200</td>
<td>WELD SS PIPING</td>
<td>68</td>
<td>166.7 hrs</td>
<td>500</td>
</tr>
<tr>
<td>79</td>
<td>2300</td>
<td>DISASSEMBLE PIPE FOR INSPECTION</td>
<td>78</td>
<td>12.5 hrs</td>
<td>50</td>
</tr>
<tr>
<td>80</td>
<td>2400/2500</td>
<td>INSPECT PIPE AT QC</td>
<td>79</td>
<td>0.33 days</td>
<td></td>
</tr>
<tr>
<td>81</td>
<td>2600</td>
<td>HYDRO TEST OF SS PIPING AT STACK</td>
<td>80</td>
<td>26.7 hrs</td>
<td>80</td>
</tr>
<tr>
<td>82</td>
<td>2800/2900</td>
<td>INSPECT, PASSIVATE</td>
<td>81</td>
<td>0.33 days</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>3100</td>
<td>LAND THE LMRP 1ST TIME</td>
<td>44,45,46,82,157,158,159,</td>
<td>1 hr</td>
<td>4</td>
</tr>
<tr>
<td>84</td>
<td>3200</td>
<td>FIT FINE ALIGNMENTS</td>
<td>83</td>
<td>0.83 days</td>
<td>40</td>
</tr>
<tr>
<td>94</td>
<td>3300</td>
<td>FIT WETMATES AND C/K STABS</td>
<td>84</td>
<td>0.5 days</td>
<td>24</td>
</tr>
<tr>
<td>109</td>
<td>3400</td>
<td>INSTALL FINE ALIGNMENTS AND C/K STABS</td>
<td>94</td>
<td>20 hrs</td>
<td>40</td>
</tr>
<tr>
<td>110</td>
<td>3500</td>
<td>FIT ACOUSTIC STABS</td>
<td>109</td>
<td>0.33 days</td>
<td>16</td>
</tr>
<tr>
<td>117</td>
<td>3600</td>
<td>FIT LOWER AND MIDDLE CHOKE AND KILL SPLS</td>
<td>7,12</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>118</td>
<td>3700</td>
<td>WAIT ON W/O TO WELD THE SPLS</td>
<td>117</td>
<td>1 day</td>
<td></td>
</tr>
<tr>
<td>119</td>
<td>3700</td>
<td>INSTALL LOWER AND MIDDLE C/K SPLS</td>
<td>118</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>120</td>
<td>3800</td>
<td>FIT UPPER C/K SPLS</td>
<td>110,119,</td>
<td>0.28 days</td>
<td>20</td>
</tr>
<tr>
<td>124</td>
<td>3900</td>
<td>STRUCTURAL WELDING (80%)</td>
<td>120,124,</td>
<td>25 hrs</td>
<td>100</td>
</tr>
<tr>
<td>125</td>
<td>4000</td>
<td>STRUCTURAL WELDING (20%)</td>
<td>119</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>127</td>
<td>4400</td>
<td>PODS, POD BOWLS, STABS AND SPLS</td>
<td>125,126,</td>
<td>0.21 days</td>
<td>20</td>
</tr>
<tr>
<td>133</td>
<td>4500</td>
<td>INSTALL POD FEMALE BOWLS</td>
<td>84</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>134</td>
<td>4600</td>
<td>REMOVE POD BOWLS, DRILL HOSES</td>
<td>127,133,</td>
<td>2.7 hrs</td>
<td>8</td>
</tr>
<tr>
<td>135</td>
<td>4700</td>
<td>REINSTALL POD BOWLS AND SECONDARIES</td>
<td>134</td>
<td>0.55 days</td>
<td>40</td>
</tr>
<tr>
<td>138</td>
<td>4800</td>
<td>RESASSEMBLE PIPING</td>
<td>82</td>
<td>20 hrs</td>
<td>80</td>
</tr>
<tr>
<td>139</td>
<td>4900</td>
<td>FAILSAFES</td>
<td>7,12</td>
<td>15 hrs</td>
<td>30</td>
</tr>
<tr>
<td>140</td>
<td>5000</td>
<td>MEASURE AND BUILD HOSES</td>
<td>49,51,52,53,139</td>
<td>60 hrs</td>
<td>180</td>
</tr>
<tr>
<td>141</td>
<td>5100</td>
<td>TEST HOSES</td>
<td>140</td>
<td>20 hrs</td>
<td>40</td>
</tr>
<tr>
<td>142</td>
<td>5200</td>
<td>FIT TUBING</td>
<td>44,46,53,139</td>
<td>53.3 hrs</td>
<td>160</td>
</tr>
<tr>
<td>143</td>
<td>5300</td>
<td>TEST TUBING</td>
<td>142</td>
<td>26.7 hrs</td>
<td>80</td>
</tr>
<tr>
<td>144</td>
<td>5400</td>
<td>LOG AND INSTALL TUBING</td>
<td>143</td>
<td>40 hrs</td>
<td>120</td>
</tr>
<tr>
<td>145</td>
<td>5500</td>
<td>INSTALL HOSES LWR STK</td>
<td>135,138,141,144,</td>
<td>40 hrs</td>
<td>120</td>
</tr>
<tr>
<td>146</td>
<td>5600</td>
<td>CHARGE DCB BOTTLES AND AC. BOTTLES</td>
<td>44</td>
<td>50 hrs</td>
<td>100</td>
</tr>
<tr>
<td>147</td>
<td>5700</td>
<td>ANODES/END</td>
<td>145,146,</td>
<td>1.25 days</td>
<td>60</td>
</tr>
</tbody>
</table>

Table 12: Standard Configurable Stack Assembly Sequence-Lower Stack
### Table 13: Standard Configurable Stack Assembly Sequence - LMRP

<table>
<thead>
<tr>
<th>ID</th>
<th>OP #</th>
<th>Task Name</th>
<th>Predecessors</th>
<th>Standard Assembly Duration</th>
<th>Standard Assembly Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>149</td>
<td>200</td>
<td>INSTALL ALIGNMENT RING</td>
<td></td>
<td>10.67 hrs</td>
<td>32</td>
</tr>
<tr>
<td>150</td>
<td>300</td>
<td>INSTALL LOCKING RING ON SBOP</td>
<td></td>
<td>2.67 hrs</td>
<td>8</td>
</tr>
<tr>
<td>151</td>
<td>400</td>
<td>LMRP LEGS, TRUSSES, COMP. BEAMS AND BRACES</td>
<td></td>
<td>37.5 hrs</td>
<td>150</td>
</tr>
<tr>
<td>152</td>
<td>500</td>
<td>ALIGN AND TORQUE SBOP TO CONNECTOR</td>
<td>149, 150</td>
<td>21.3 hrs</td>
<td>64</td>
</tr>
<tr>
<td>153</td>
<td>600</td>
<td>ALIGN AND TORQUE SBOP AND CONNECTOR TO LMRP</td>
<td>152</td>
<td>8 hrs</td>
<td>24</td>
</tr>
<tr>
<td>154</td>
<td>700</td>
<td>LAND 2ND SBOP ON 1ST SBOP (if two SBOPs)</td>
<td>153</td>
<td>2.67 hrs</td>
<td>8</td>
</tr>
<tr>
<td>155</td>
<td>800</td>
<td>INSTALL BLIND FLANGES ON SBOP</td>
<td>153, 154</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>156</td>
<td>900</td>
<td>INSTALL FEMALE ALIGNMENTS</td>
<td>153, 154</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>157</td>
<td>1000</td>
<td>INSTALL WETMATE</td>
<td>156</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>158</td>
<td>1100</td>
<td>INSTALL C/K STABS</td>
<td>157</td>
<td>33.3 hrs</td>
<td>100</td>
</tr>
<tr>
<td>159</td>
<td>1200</td>
<td>INSTALL ACOUSTIC STABS</td>
<td>158</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>160</td>
<td>1400</td>
<td>GAS BLEED ASSEMBLY</td>
<td>159</td>
<td>20 hrs</td>
<td>60</td>
</tr>
<tr>
<td>161</td>
<td>1500</td>
<td>STRUCTURAL WELDING LMRP</td>
<td></td>
<td>75 hrs</td>
<td>300</td>
</tr>
<tr>
<td>162</td>
<td>1800</td>
<td>FIT PODS</td>
<td>161</td>
<td>7.5 hrs</td>
<td>30</td>
</tr>
<tr>
<td>163</td>
<td>1900</td>
<td>INSTALL PODS</td>
<td>161, 162, 125, 126</td>
<td>2.67 hrs</td>
<td>8</td>
</tr>
<tr>
<td>164</td>
<td>2000</td>
<td>FABRICATE SHUTTLE VALVE TREES (LMRP)</td>
<td></td>
<td>30 hrs</td>
<td>120</td>
</tr>
<tr>
<td>165</td>
<td>2100</td>
<td>INSTALL SHUTTLE VALVE TREES (LMRP)</td>
<td>164</td>
<td>6.67 hrs</td>
<td>20</td>
</tr>
<tr>
<td>166</td>
<td>2200</td>
<td>MEASURE AND BUILD HOSES (LMRP)</td>
<td>165</td>
<td>40 hrs</td>
<td>120</td>
</tr>
<tr>
<td>167</td>
<td>2300</td>
<td>TEST HOSES (LMRP)</td>
<td>166</td>
<td>20 hrs</td>
<td>40</td>
</tr>
<tr>
<td>168</td>
<td>2400</td>
<td>INSTALL HOSES LMRP</td>
<td>167, 135</td>
<td>30 hrs</td>
<td>90</td>
</tr>
<tr>
<td>169</td>
<td>2500</td>
<td>RIGIT CONDUIT</td>
<td>169</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>170</td>
<td>2600</td>
<td>FIT TUBING</td>
<td>170</td>
<td>33.3 hrs</td>
<td>100</td>
</tr>
<tr>
<td>171</td>
<td>2700</td>
<td>TEST TUBING</td>
<td>170</td>
<td>6.7 hrs</td>
<td>20</td>
</tr>
<tr>
<td>172</td>
<td>2800</td>
<td>INSTALL UPPER PLATFORM</td>
<td>170</td>
<td>21 hrs</td>
<td>84</td>
</tr>
<tr>
<td>173</td>
<td>2900</td>
<td>INSTALL PISTON BOTTLE BKTS AND PISTON BOTTLES</td>
<td>172</td>
<td>16.7 hrs</td>
<td>50</td>
</tr>
<tr>
<td>174</td>
<td>3000</td>
<td>INSTALL ROV PANELS (LMRP)</td>
<td>172</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>175</td>
<td>3100</td>
<td>INSTALL LADDER ASSEMBLY</td>
<td>172</td>
<td>5.3 hrs</td>
<td>16</td>
</tr>
<tr>
<td>176</td>
<td>3200</td>
<td>CUT PIPING LMRP</td>
<td>173</td>
<td>25 hrs</td>
<td>50</td>
</tr>
<tr>
<td>177</td>
<td>3300</td>
<td>WELD PIPING LMRP</td>
<td>169, 176, 135, 166</td>
<td>166.7 hrs</td>
<td>500</td>
</tr>
<tr>
<td>178</td>
<td>3400</td>
<td>DISASSEMBLE PIPE FOR INSPECTION LMRP</td>
<td>177</td>
<td>10 hrs</td>
<td>40</td>
</tr>
<tr>
<td>179</td>
<td>3500/3600</td>
<td>INSPECT PIPE AT QC LMRP</td>
<td>178</td>
<td>0.33 days</td>
<td>10</td>
</tr>
<tr>
<td>180</td>
<td>3700</td>
<td>HYDRO TEST OF SS PIPING AT STACK (LMRP)</td>
<td>179</td>
<td>26.7 hrs</td>
<td>80</td>
</tr>
<tr>
<td>181</td>
<td>3900/4000</td>
<td>INSPECT (LMRP)</td>
<td>180</td>
<td>0.33 days</td>
<td>80</td>
</tr>
<tr>
<td>182</td>
<td>4200</td>
<td>REASSEMBLE PIPING</td>
<td>181</td>
<td>15 hrs</td>
<td>60</td>
</tr>
<tr>
<td>183</td>
<td>4300</td>
<td>INSTALL TUBING LMRP</td>
<td>171, 174, 135, 176</td>
<td>10 hrs</td>
<td>30</td>
</tr>
<tr>
<td>184</td>
<td>4400</td>
<td>INSTALL WELLBORE SENSOR</td>
<td>183</td>
<td>4 hrs</td>
<td>8</td>
</tr>
<tr>
<td>185</td>
<td></td>
<td>END OF OPERATIONS (USUALLY AT PORT)</td>
<td>147, 155, 160, 168, 175, 184, 182</td>
<td>0 hrs</td>
<td>0</td>
</tr>
<tr>
<td>186</td>
<td></td>
<td>OTHER OPERATIONS (USUALLY AT PORT)</td>
<td>185</td>
<td>176 hrs</td>
<td>0</td>
</tr>
</tbody>
</table>

| LMRP | 40.08 days | 2292 |

### Table 14: Standard Configurable Stack Assembly Sequence - Testing & Tear Down

<table>
<thead>
<tr>
<th>ID</th>
<th>OP #</th>
<th>Task Name</th>
<th>Predecessors</th>
<th>Standard Assembly Duration</th>
<th>Standard Assembly Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>188</td>
<td>400</td>
<td>PRELIMINARY TEST</td>
<td>185</td>
<td>4.76 days</td>
<td>800</td>
</tr>
<tr>
<td>192</td>
<td>600</td>
<td>QC INSPECTION</td>
<td>188</td>
<td>1 hr</td>
<td>80</td>
</tr>
<tr>
<td>193</td>
<td>700</td>
<td>THIRD PARTY INSPECTION</td>
<td>192</td>
<td>1 hr</td>
<td>80</td>
</tr>
<tr>
<td>194</td>
<td>800</td>
<td>STACK TEST</td>
<td>193</td>
<td>7 days</td>
<td>672</td>
</tr>
<tr>
<td>200</td>
<td>1200</td>
<td>QC REPORTS INSPECTION</td>
<td>194</td>
<td>1 hr</td>
<td>800</td>
</tr>
<tr>
<td>201</td>
<td>1800</td>
<td>TEAR DOWN</td>
<td>200</td>
<td>5 days</td>
<td>700</td>
</tr>
<tr>
<td>208</td>
<td>1400</td>
<td>TOUCH UP PAINT</td>
<td>200</td>
<td>1 days</td>
<td>48</td>
</tr>
<tr>
<td>209</td>
<td>1600</td>
<td>ATTACH NAME PLATES AND PROJECT TAGS</td>
<td>201</td>
<td>2 hrs</td>
<td>2</td>
</tr>
<tr>
<td>210</td>
<td>2000</td>
<td>FINAL VISUAL QC INSPECTION</td>
<td>209</td>
<td>1 hr</td>
<td>800</td>
</tr>
</tbody>
</table>

| TESTING AND TEAR DOWN | 2,148 | 17.01 days | 2222 |

---

40
Based on the precedence constraints and standard operation hours obtained from the vetting process, the ideal project duration for a configurable stack, i.e. including LMRP, Lower Stack and Testing and Tear Down, was found to be approximately 12 weeks, Figure 14 (assuming two 8 hrs. daily shifts and a 6 day work week). This ideal assembly time of 12 weeks can be compared to the actual assembly time of the completed configurable stacks in Table 15.

![Figure 14: Standard Assembly Sequence Gantt chart](image)
### Conventional Stacks

<table>
<thead>
<tr>
<th>Project</th>
<th>Lead Time</th>
<th>Actual Assembly Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PRIDE IV</td>
<td>10 wks</td>
<td>7,220 hrs</td>
</tr>
<tr>
<td>QGOG I</td>
<td>18 wks</td>
<td>10,886 hrs</td>
</tr>
<tr>
<td>QGOG II</td>
<td>18 wks</td>
<td>11,576 hrs</td>
</tr>
</tbody>
</table>

### Configurable Stacks

<table>
<thead>
<tr>
<th>Stack Type</th>
<th>Lead Time</th>
<th>Actual Assembly Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Noble</td>
<td>18 wks</td>
<td>11,508 hrs</td>
</tr>
<tr>
<td>Noble Spare</td>
<td>23 wks</td>
<td>12,723 hrs</td>
</tr>
</tbody>
</table>

Table 15: Actual Project Duration

From the Table 15 it could be seen that the actual project duration is 1.5 – 2 times as long as the ideal project duration. Based on this calculation and the Operation Flow Analysis described in Chapter 2, it could be concluded that some form of assembly delay typically accounts for about 33% of the actual project duration. Hence reducing assembly delay in the assembly process could help to reduce assembly lead time.

However, assembly delays could be attributed to delays in either component delivery or due to rework inefficiency within the downstream, assembly operation. In order to reduce the overall assembly delays, the root cause of these delays had to be analyzed. A Delay Log database was developed to capture all assembly pad delays and to identify their root causes (Pizano, C., 2013).

#### 4.2.2 Delay Log

One of the problems identified at NOV WLY facility was the absence of a formal system to record component delays and engineering changes causing assembly delays. A Delay Log was designed and implemented to capture any deviations of the actual assembly procedure from the standardized procedure (Pizano, C., 2013). At the time of writing most of the Bill of Material (BOM) and Engineering Change Requests (ECR) were made informally through informal emails exchanged between the final assembly staff, upstream project management and component acquisition staff. These required changes were not typically incorporated into the new project plans resulting in repeated delays in future assemblies. Waiting for the same Engineering Changes and assembly reworks. The Delay Log Sheet implemented at NOV – WLY primarily serves two purposes:
i. It provided a means to identify the root causes of the delays. Once the cause of the delays are identified, they can be segregated into various categories such as vendor, engineering, controls etc. based on the origin of these delays. The percentage contribution of each category of delays to the overall assembly delay can be estimated. This upstream feedback for downstream assembly delays is critical to mitigating future assembly delays.

ii. It provides a formal record of the delays and the actions taken. The record of assembly delays and the corresponding corrective actions taken, acts as a guideline to be used when similar issues are encountered during future projects. Similarly, these records can also help to reduce rework times, by incorporating changes in the Bill of Materials and manufacturing drawings for new projects, based on the previous changes made on similar kinds of projects.

The first Delay Log was implemented simultaneously for 6 configurable stack assembly projects in January 2013, Figure 15.

![Sample Delay Log Sheet](image)

**Figure 15: Sample Delay Log Sheet**

The assembly delays results in the labor either remaining idle or being utilized for non-productive work. The monetary values of these delays were estimated by considering the labor cost incurred for the idle and non-productive workforce during the delays, Table 16. Based on an initial analysis of the Delay Log implemented for the 6 projects, Figure 16, the following observations were made. Engineering delays, accounted for 35% of the total delays were the main constituent to the assembly delays. Delays due to vendors and the Controls Department accounted for 20% and 19% of the assembly delays respectively. From this analysis of the Delay Log it was concluded that the upstream delays (non-assembly) had a very large impact on the
assembly delays. Hence it was decided to focus on building tools that could be used to reduce these upstream delays, then impact the final stack assembly time.

<table>
<thead>
<tr>
<th>Delay Root Cause (January 2013 – June 2013)</th>
<th>cost of delays ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engineering</td>
<td>3918600</td>
</tr>
<tr>
<td>Vendor</td>
<td>2232720</td>
</tr>
<tr>
<td>Controls</td>
<td>2084040</td>
</tr>
<tr>
<td>Lockwood</td>
<td>1653120</td>
</tr>
<tr>
<td>Other</td>
<td>846720</td>
</tr>
<tr>
<td>Shop (NOV)</td>
<td>272160</td>
</tr>
<tr>
<td>Undefined</td>
<td>141120</td>
</tr>
<tr>
<td>Galena Park</td>
<td>70560</td>
</tr>
<tr>
<td>QC</td>
<td>47880</td>
</tr>
<tr>
<td>Receiving/Communication</td>
<td>15120</td>
</tr>
</tbody>
</table>

Table 16: Cost of delays (direct labor cost)

Developing and implementing tools that could directly reduce the delays at the upstream side, and hence improve the throughput of the stack pad is the long term goal of the NOV MS project. However implementing ideas that provide tangible results quickly is most desirable because the interests of participants grow weak if
substantial gains are not realized within 12 weeks (Singh, V. P., 2012). Therefore, it was decided to prioritize the creation of tools that could reduce the impact of upstream delays, with a focus on immediate reduction of the assembly lead times. Hence the Assembly Delay Impact tool was developed, to accurately and dynamically plan and schedule assembly activities, incorporating up-to-date information on expected assembly delays.

4.2.3 Assembly Operation Network Diagram

The data for the Assembly Delay Impact Tool (ADIT) was obtained from the Standard Assembly Sequence generated using the vetting process. As an initial step towards developing ADIT, an assembly operations network diagrams based on the precedence constraints were created from the Standard Assembly Sequence. Separate network diagrams were created for the Lower Stack, LMRP and the Testing and Tear Down operations, Figure 17, 18 & 19. A network diagram was developed, to better illustrate the operation precedence compared to the Standard Assembly Sequence created in tabular format. This network diagram was vetted by the NOV team to ensure the accuracy of the operation sequence and the precedence requirements.
Figure 17. Lower Stack Operation Network Diagram
Figure 18. LMRP Operation Network Diagram
4.2.4 **Assembly Delay Impact Tool (ADIT)**

The ADIT is a planning and scheduling tool that considers the upstream and downstream delays while generating a dynamic stack pad assembly schedule for an individual configurable stack assembly. The tool is in the form of a Macro Enabled Excel Workbook. The tool has user forms created using Excel VBA in order to make the tool user friendly. It systematically guides the user through the various steps of data entry and report generation. The tool has been created in Microsoft 2010 format; however it is compatible with the earlier versions of Microsoft Office. Excel was selected as the platform for implementing the tool for the following reasons:

i. **Compatibility** - The systems at NOV runs on Windows Operating System, which has Microsoft Office installed by default. Therefore the Assembly Delay Impact Tool could be run on any NOV system.

ii. **User-friendly** - Microsoft Excel is widely used software both at NOV and around the world. Hence ADIT can be used at NOV with minimal operator training.

iii. **Integration with other software** – The Glovia and Kronos production management tools used at NOV generate reports in Excel format. Most of the other reports pertaining to assembly activities at NOV are also generated in Excel format. Therefore by creating ADIT in Excel, it is easier to integrate the data from any of these databases into the tool, when required.
4.2.4.1 **Critical Path Method (CPM)**

To develop the assembly schedule in ADIT The Critical Path Method (CPM) is used. CPM is a project modeling technique developed by Walker and Kelley (Kelly J.E., Walker M.R. 1959). This analysis technique is commonly used in industries with custom engineered products and services such as the construction, aerospace and software industries. In order to generate the project schedule CPM requires

i. The precedence constraint of all activities in the project

ii. The duration of each activity (D)

CPM then determines the following parameters, Earliest Start Time (EST), Earliest Finish Time (EFT), Latest Start Time (LST) and Latest Finish Time (LFT) for each project activity. The parameters are calculated using the following formulae

\[
EFT = EST + D \tag{4.1}
\]

\[
LST = LFT - D \tag{4.2}
\]

Max. Time available for a job = LFT – EST \tag{4.3}
The EST of the activity having no precedence constraint is set to zero. For an activity having one precedence constraint, the EST will be the EFT of the preceding activity with precedence, while for an activity having more than one precedence constraint; the EST will be the maximum of the EFT’s of all of the preceding activities.

The LST of the activity having no subsequent activity constraints will be the maximum of EFT’s of all activities having no successive activity constraints. For an activity which has only one succeeding activity, its LFT will be the LST of the succeeding activity. For an activity which has more than one succeeding activity, its LFT will be maximum of the LST’s of all of the succeeding activities.

The CPM, apart from generating the schedule of a project, also helps to determine the “critical path” of a project. The contiguous path of critical activity through the project from origin to terminus is called as Critical Path (Kelly J.E, Walker M.R. 1959). If the maximum time available for an activity is equal to its duration then this activity is called a critical activity. Any delays in the critical path will result in the delay of the overall project as there is no slack time available for that activity. The addition of delays in activities could cause a change in the critical path.

4.2.4.2 No Delay and Delay Operations

The CPM can be used to determine complete project schedule, including tracking of individual activities in the individual departments through which the product flows. In the case of the Stack Pad assembly, CPM can be used to determine schedules within the assembly department. Here the individual assembly operations are considered as individual activities and the duration of assembly operations are considered as the duration of activities. Duration of individual operations are estimated using the following formula

\[
\text{Duration} = \frac{\text{Standard Hours}}{\text{Number of Operators}}
\]  

(4.4)

The Standard Hours and Number of Operators for the individual operations have been obtained from the Standard Assembly Sequence developed and vetted by key NOV staff.
The following delay scenarios were investigated as part of the analysis:

i) No delay

ii) With delays

In the first scenario, the assembly schedule with no delays is created in the “wo_delay_hrs” sheet in the Excel Work Book, Figure 21 & 22. Here a total of 98 major assembly operations including Lower Stack, LMRP and Testing & Tear Down are considered (ID#3 – ID#210). This scenario provides the user with the ideal no delay, standard assembly hour schedule for a Stack Pad assembly.

<table>
<thead>
<tr>
<th>Earliest Start Time</th>
<th>OPT #</th>
<th>Earliest Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latest Start Time</td>
<td>Opt. Time</td>
<td>Latest Finish Time</td>
</tr>
</tbody>
</table>

**Figure 21: ADIT no delay/delay sheet format**

<table>
<thead>
<tr>
<th>Earliest Start Time</th>
<th>OPT #</th>
<th>Earliest Finish Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Latest Start Time</td>
<td>Opt. Time</td>
<td>Latest Finish Time</td>
</tr>
</tbody>
</table>

**Figure 22: ADIT wo_delay_hrs sheet**

In the second scenario, the assembly schedule with delays is created in the “delay_hrs” sheet in the Excel Work Book, Figure 23. For the 98 operations including, Lower Stack assembly, LMRP assembly and Testing and Tear Down are considered (ID#3 – ID#210). However in this scenario additional 135 delays (delay
operations) are also included. Here it is assumed that any two operations linked by a precedence constraint can have a delay operation between them Figure 24. For example, the operation ID#7 has Operation ID#3 as its precedence constraint. Therefore a delay operation D(3-7) is inserted between operation ID#3 and ID#7. For delay operation D(3-7), operation ID#3 will be its preceding operation and operation ID#7 will be its succeeding operation. Any delays in beginning operation ID#3, and any delays within operation ID#3 will be included in delay operation D(3-7). The “wo_delay_hrs” sheet and the “delay_hrs” sheet in ADIT provide the schedule of individual assembly operations in terms of total hours.

<table>
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<th></th>
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<th>57</th>
<th>37</th>
<th>70</th>
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<table>
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<tr>
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<td>D(17-28)</td>
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<td>436</td>
<td>0</td>
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<td></td>
</tr>
</tbody>
</table>

Figure 23: ADIT delay_hrs sheet
4.2.4.3 Part List

In the analysis done using the ADIT, two types of delays have been considered. First is the delay due to late arrival of components required for a particular operation and second is the delay within the assembly operation itself caused by reworks or various other reasons. One assumption that has been made for calculating the delay is that a particular assembly operation begins, once all the parts associated to that operation are available.

A default list of the major components associated with each assembly operation has been created in the part sheet. The list is referred to as a part list instead of a Bill of Material as it is not an exhaustive list of the components that are required to complete the assembly. Because delays can be associated with a specific component within an operation number, the user has the option to add additional delayed components that are part of the operation in the part sheet if required.

In order to assist the user in updating the delayed arrival dates of components a macro “delay” has been created using VBA. Clicking the “Add delay” tab on the “Sequence&Labor” sheet activates this macro. The macro first generates a “delay” user form containing the list of all Assembly operations, Figure 25. Once the user selects the delayed assembly operation and clicks the OK tab, it generates a

Figure 24: Example of network diagram with delays
“Start/Finish” user form, Figure 26. The “Start/Finish” user form provides the user with two options, either to change the start time of the operation or to change the completion time of the operation.

If the user selects the option to change the start time of the operation from the “Start/Finish” user form, it generates a dynamic “Part list Opt#” user form which contains the part list associated with the selected operation, Figure 27. The part list in the “Part list Opt#” user form contains “Misc. Part” to add arrival dates for parts that were not included in the default part list. The arrival date of each part is provided inside the parenthesis under the corresponding part name, (For a new project the default values in the parenthesis will be “N/A”). Besides each part in the “Part list Opt#” user form an “Enter Arrival Date” tab has been provided. On clicking the “Enter Arrival Date” an “Arrival Date” user form is generated, where the user can select the delayed arrival date form the drop down menu, Figure 28.
If the user selects the option to change the completion time of the operation from the “Start/Finish” user form, it generates the “Assy Delay Opt#” user form which contains an “Enter completion date” tab, Figure 29. Similar to the “Part list Opt#” user form, here the completion date of each part is provided inside the parenthesis under “Assembly Delay”, (For a new project, the default values in the parenthesis will be “N/A”). On clicking the “Enter completion date” on the “Assy Delay Opt#” user form, an “Assy. Date” user form is generated, where the user can select the delayed assembly completion date form the drop down menu, Figure 30.
The selections made in the user form updates the part sheet with the latest delay dates. The data from the part sheet is then combined with the data from the “wo_delay_hrs” sheet to generate the new assembly schedule with delays.

4.2.4.4 Delay Calculation

The ADIT generates a dynamic assembly schedule to be used by planners and expeditors at NOV. The required output should be in terms of dates. However the input used for the ADIT is the operation duration in terms of assembly hours. Hence a series of calculations are required to convert the assembly hours into dates considering various factors such as number of weekly working days and the duration of the shift per day. Another challenge in generating an updated schedule is in identifying the weekends and other non-working days and excluding them from the schedule.

In order to generate the project schedule an important input required from the user is the anticipated project or assembly start date. In order to assist the user in inputting this information a macro “Start_Date” has been created using VBA. Clicking the “New Project click” tab on the “Sequence&Labor” sheet activates this macro.
macro first generates a “Project Details” user form where the user is prompted to enter project details such as the Project Name, Project Sales Order number (SO) and the Pad number, Figure 31. On completing this user form and clicking the “OK” tab in the user form, it generates the “Start Date” user form from where, the project start date can be selected from a drop down menu, Figure 32. On completing this user form and clicking the “OK” tab on “Start Date” user form, generates the “Shift/Work days” user form, Figure 33. This user form provides the user with options to select the shift duration and weekly working days.

Figure 31: ADIT Project Details user form

Figure 32: ADIT Start Date user form
In order to generate the no delay schedule considering the weekends and shift duration the following calculations were performed:

- **PSD** – Project Start Date
- **SHD** – Shift Duration
- **WD** – Number of Working days / week
- **PSY** – Project Start Day (if PSD = Monday (PSY=0), Tuesday(PSY=1), Wednesday(PSY=2), Thursday(PSY=3), Friday(PSY=4), Saturday(PSY=5), Sunday(PSY=6))
- **WND** – Number of nonworking days (if WD = 5(WND = 2), 6(WND = 1), 7(WND = 0))
- **ECDi** – Earliest Completion Date
- **LCDi** – Latest Completion Date
- **EFTi** – Earliest Finish Time
- **LFTi** – Latest Finish Time
- **ESTi** – Earliest Start Time
- **NWEi** – Number of Weeks from PSD to EFTi (Earliest Finish)
- **NWLi** – Number of Weeks from PSD to LFTi (Latest Finish)

\[ i = \text{OP ID#}3 - \text{OP ID#}210 \]

\[ NWEi = \frac{\lfloor \text{EFTi} / (2 \times \text{SHD}) + \text{PSY} \rfloor}{\text{WD}} \tag{4.5} \]

\[ NWLi = \frac{\lfloor \text{LFTi} / (2 \times \text{SHD}) + \text{PSY} \rfloor}{\text{WD}} \tag{4.6} \]
ECDi = PSD + EFTi / (2 x SHD) + WND x NWEi  
LCDi = PSD + LFTi / (2 x SHD) + WND x NWLi

Delayed arrival date and delayed completion date for an operation, are provided by the users in date format. Hence these delay dates have to be converted to delay hours before they can be used in CPM. Once the delay dates are converted into delay hours they can be added as the duration of the corresponding delay operation in the “delay_hrs” sheet. However there are certain factors that have to be considered while converting the delay dates into delay hours as follows

i. Check whether the delayed arrival date is a non-working day, if so the operation start date will be shifted to the next working day. Hence the non-working days will also be considered toward the delay hours.

ii. Check whether the delayed completion date is a non-working day, if so the operation completion time will be shifted to the next working day. Hence the non-working days will also considered toward the delay hours.

DADi - Delayed Arrival Date
DAYi – Delayed Arrival Day
DCDi - Delayed Completion Date
DCYi - Delayed Completion Day

NWAi – Number of Weeks from PSD to DADi (delayed arrival)
NWDi – Number of Weeks from PSD to DCDi (delayed completion)
NNAi – Number of Non-Working days from PSD to DADi (delayed arrival)
NNDi – Number of Non-Working days from PSD to DCDi (delayed completion)

DAi – Total Delay due to delayed arrival date in hrs
DCi - Total Delay due to delayed completion date in hrs

ADI – Actual Total Delay, (MAX (DAi, DCi))
i = OP ID#3 to OP ID# 210
DYSA (x) – Delayed Day Saturday, (Assigns 0 OR 1 based on whether the arrival/completion day is a Saturday and whether Saturday is a working day
   { If [ x = “Saturday” ] AND If [WD=5(DYSA = 1), WD=6(DYSA = 0), WD=7(DYSA = 0) ] }, where x = DAYi , DCYi

DYSU (x) – Delayed Day Sunday, (Assigns 0 OR 1 based on whether the arrival/completion day is a Sunday and whether Sunday is a working day
   { If [x = “Sunday” ] AND If [WD=5(DYSU = 1), WD=6(DYSU = 0), WD=7(DYSU = 0) ] }, where x = DAYi , DCYi

DDC(y) – Delayed Day Checker, Checks whether y is a “Saturday” or “Sunday”,
   { If [ y = “Saturday” (DYS (y)), y = “Sunday” (DYSU (y)] },
   where y = DAYi , DCYi

NNAi = ( DYSA (DADI) x NWAi ) + ( DYSUi (DADI) x NWAi ) \hspace{1cm} (4.9)
NNDi = ( DYSAi (DCDi) x NWDi ) + ( DYSUi (DCDi) x NWDi ) \hspace{1cm} (4.10)
DAi = [(DADI - PSD + ESTi /(2 x SHD)) x (2 x SHD)] - [( NNAi - DDC(DAYi)) x ( 2 x SHD)] \hspace{1cm} (4.11)
DCi = [( (DCDi - PSD + EFTi /(2 x SHD)) x (2 x SHD)- [( NNDi - DDC(DCYi)) x ( 2 x SHD)] \hspace{1cm} (4.12)

The resulting ADi, the actual total delay is in terms of hours and therefore can be added as the duration of the corresponding delay operation in “delay_hrs” sheet. As in the case of the no delay schedule, in order to generate the delay schedule considering weekends and shift duration, the following calculations were done.
ECDDi – Earliest Completion Date with delays
LCDDi – Latest Completion Date with delays
EFTDi – Earliest Finish Time with delays
LFTDi – Latest Finish Time with delays
ESTDi – Earliest Start Time with delays
NWEDi – Number of Weeks from PSD to EFTDi (Earliest Finish)
NWLDi – Number of Weeks from PSD to LFTDi (Latest Finish)
i = OP ID# D(3-7) – OP ID# D(210)

NWEDi = [EFTDi / (2 x SHD) + PSY] / WD 
(4.13)
NWLDi = [LFTDi / (2 x SHD) + PSY] / WD 
(4.14)
ECDDi = PSD + EFTDi / (2 x SHD) + WND x NWEDi 
(4.15)
LCDDi = PSD + LFTi / (2 x SHD) + WND x NWLDi 
(4.16)

ADIT provides the user with an option to generate a delay report using the macro created using VBA. A delay report is a summary of the delayed operations. It provides the delayed operation numbers, name of the delayed part and delayed arrival or completion date. The “delay_report” macro is activated upon clicking the Delay Report tab on the “Sequence&Labor” sheet. The delay report is created on the “delay_report” sheet within the ADIT workbook, Figure 34.

<table>
<thead>
<tr>
<th>OPT #</th>
<th>PART</th>
<th>S/F DATE</th>
<th>OPT #</th>
<th>PART</th>
<th>S/F DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>200_LWR</td>
<td>LWR SPIDER</td>
<td>3-Jan-13</td>
<td>400_LWR</td>
<td>LWR MINI SPIDER</td>
<td>7-Jan-13</td>
</tr>
<tr>
<td>200_LWR</td>
<td>Misc. Part</td>
<td>6-Jan-13</td>
<td>400_LWR</td>
<td>UPPER BOP (UPR TRIPLE)</td>
<td>11-Jan-13</td>
</tr>
</tbody>
</table>

Figure 34: Sample ADIT Delay Report
4.2.4.5 Critical Path

The critical path of operations in the “delay_hrs” sheet is determined using the macro “Critical_Path” created using VBA. Each time the “Critical Path tab” on the “Sequence&Labor” sheet is clicked, it activates the macro. The macro determines the critical operations and highlights them in yellow on the “delay_hrs” sheet. It also highlights the critical operations in yellow on the “Sequence&Labor” sheet. The macro then creates a critical path report in the “critical_paths” sheet. The “critical path” sheet contains the Operation ID and Operation number of all critical operations. It also records the date and time at which the critical path is calculated, Figure 35. This sheet contains the record of all the critical paths generated during the time line of the project.

<table>
<thead>
<tr>
<th>CRITICAL PATHS</th>
<th>7/1/2013 10:43</th>
<th>7/1/2013 10:43</th>
</tr>
</thead>
<tbody>
<tr>
<td>ID</td>
<td>OP#</td>
<td>ID</td>
</tr>
<tr>
<td>3</td>
<td>200_LWR</td>
<td>3</td>
</tr>
<tr>
<td>8</td>
<td>400_LWR</td>
<td>8</td>
</tr>
<tr>
<td>13</td>
<td>600_LWR</td>
<td>13</td>
</tr>
<tr>
<td>17</td>
<td>700_LWR</td>
<td>17</td>
</tr>
<tr>
<td>28</td>
<td>800_LWR</td>
<td>28</td>
</tr>
<tr>
<td>37</td>
<td>900_LWR</td>
<td>37</td>
</tr>
<tr>
<td>53</td>
<td>1000_LWR</td>
<td>44</td>
</tr>
<tr>
<td>68</td>
<td>1100_LWR</td>
<td>83</td>
</tr>
<tr>
<td>78</td>
<td>1200_LWR</td>
<td>84</td>
</tr>
<tr>
<td>79</td>
<td>1300_LWR</td>
<td>94</td>
</tr>
<tr>
<td>80</td>
<td>1400/2500_LWR</td>
<td>109</td>
</tr>
<tr>
<td>81</td>
<td>1500_LWR</td>
<td>110</td>
</tr>
<tr>
<td>82</td>
<td>2700/2800/2900/3000_LWR</td>
<td>120</td>
</tr>
<tr>
<td>83</td>
<td>3100_LWR</td>
<td>127</td>
</tr>
<tr>
<td>84</td>
<td>3200_LWR</td>
<td>134</td>
</tr>
<tr>
<td>94</td>
<td>3300_LWR</td>
<td>135</td>
</tr>
<tr>
<td>109</td>
<td>3400_LWR</td>
<td>147</td>
</tr>
<tr>
<td>110</td>
<td>3500_LWR</td>
<td>177</td>
</tr>
<tr>
<td>120</td>
<td>3800_LWR</td>
<td>178</td>
</tr>
<tr>
<td>127</td>
<td>4400_LWR</td>
<td>179</td>
</tr>
<tr>
<td>134</td>
<td>4600_LWR</td>
<td>180</td>
</tr>
<tr>
<td>135</td>
<td>4700_LWR</td>
<td>181</td>
</tr>
<tr>
<td>147</td>
<td>5700_LWR</td>
<td>182</td>
</tr>
<tr>
<td>177</td>
<td>3300_LMRP</td>
<td>185</td>
</tr>
<tr>
<td>178</td>
<td>3400_LMRP</td>
<td>186</td>
</tr>
<tr>
<td>179</td>
<td>3500/3600_LMRP</td>
<td>188</td>
</tr>
<tr>
<td>180</td>
<td>3700_LMRP</td>
<td>192</td>
</tr>
<tr>
<td>181</td>
<td>3800/3900/4000/4100_LMRP</td>
<td>193</td>
</tr>
<tr>
<td>182</td>
<td>4200_LMRP</td>
<td>194</td>
</tr>
<tr>
<td>185</td>
<td>opt1_LMRP</td>
<td>200</td>
</tr>
<tr>
<td>186</td>
<td>opt2_LMRP</td>
<td>201</td>
</tr>
<tr>
<td>188</td>
<td>400_TTD</td>
<td>209</td>
</tr>
<tr>
<td>192</td>
<td>600_TTD</td>
<td>210</td>
</tr>
<tr>
<td>193</td>
<td>700_TTD</td>
<td>194</td>
</tr>
<tr>
<td>200</td>
<td>1200_TTD</td>
<td>201</td>
</tr>
<tr>
<td>209</td>
<td>1600_TTD</td>
<td>210</td>
</tr>
</tbody>
</table>

Figure 35: ADIT Critical Path Report
4.2.4.6 **Dashboard - Pad Layout**

The ADIT supports the planners and supervisors at the Stack Pad in their planning and schedule assembly activities considering the upstream and downstream delays. In order to extend the use of ADIT within the stack pad, a dashboard was created which uses the data from ADIT as Key Performance Indicators (KPIs). The objective of the stack pad dashboard is to provide a simple visual tool that could be used to evaluate the status of all the projects running at the Stack Pad, Figure 36. The dashboard is in the form of a Macro Enabled Excel Workbook to make it compatible with the ADIT. It has also been created in Microsoft 2010 format. In order to update the information in the dashboard user forms, command tabs created using Excel VBA have been provided. The dashboard contains user forms to guide the users through the various steps of calculation and report preparation.

The stack pad dashboard conveys information regarding the status of the projects running at the stack pad, and the percentage of work that has been completed for the ongoing projects at the stack pad. The stack pad dashboard helps to extend the usefulness of the ADIT tool to the entire stack pad staff by providing them with a visual tool to identify projects which are running behind schedule. This would aid in early corrective action to manage assembly delays. Unlike the ADIT, the stack pad dashboard would allow users to access the status of all the stack pad projects in a single location.

The stack pad dashboard contains the stack pad layout which clearly defines the seven Pads, Jack ups, warehouse, testing rooms and the various other building at the NOV-WLY stack pad assembly area. Specific color codes have been provided to indicate the status of the Lower Stack and LMRP stacking process at each pad. The color “Green” for a pad indicates that the project in that specific pad is running as per schedule. “Orange” and “Red” indicates that there are delays in non-critical paths and critical paths respectively, while “White” indicates that there are no projects assigned to the given pad. Another KPI included in the dashboard is the percentage of work
completed at a given pad. This KPI has been represented in the form of a speedometer. The needle of the speedometer rotates from 0% completion to 100% completion in the clockwise direction as each stack project progresses.

Figure 36: Example of Stack Pad Layout Dashboard
The information in the stack pad dashboard is linked with the data in the ADIT using macros. Each pad in the layout is provided with a tab which when clicked activates the corresponding macro “PAD_#”. This macro helps to activate the delay report from the ADIT corresponding to the specific pad. The data in the dashboard is updated using the macro “Update” created using VBA. The “Update” macro is activated on clicking the “Update Layout” tab on the “Layout” sheet. This generates the “Update” user form with the list of the pads to be updated, Figure 37. Selecting the required pad and clicking the “OK” tab, automatically updates the color and the percentage value of the work completed in the dashboard, corresponding to the selected pad. In case of a missing ADIT file, an error message would be generated, Figure 38.

![Figure 37: Stack Pad Dashboard Update user form](image1)

![Figure 38: Stack Pad Dashboard Error Message (missing file)](image2)
Chapter 5

Validation of the Assembly Delay Impact Tool

The forecasting accuracy of the ADIT is validated in this chapter. In order to validate the accuracy, the ADIT was implemented on Configurable stack assembly projects. All the data including the information from the delay log sheet pertaining to the project was entered into the tool. The resulting completion date determined by ADIT with delays was compared to the actual completion date of the project.

The ADIT tool was validated by using data from 6 stack assembly projects. Table 17 shows the results of the validation. The percentage deviation is the prediction error of the model expressed as percentage of the actual project duration. The percentage deviation of the estimated date varies from 1.39% to 17.53%. The large deviation of estimated finish date in Project 4 & Project 7 could be attributed to the shorter lead time achieved as a result of implementing the best practices observed during the execution of Project 2 and Project 6 respectively; as Project 4 and Project 7 were similar to Project 2 and Project 6, and was executed for the same customer.

<table>
<thead>
<tr>
<th>Project</th>
<th>Start Date</th>
<th>Actual Finish Date</th>
<th>Finish Date (ADIT)</th>
<th>Deviation (days)</th>
<th>% Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project 1</td>
<td>11/7/2012</td>
<td>3/28/2013</td>
<td>4/3/2013</td>
<td>6.00</td>
<td>4.26</td>
</tr>
<tr>
<td>Project 2</td>
<td>11/25/2012</td>
<td>4/24/2013</td>
<td>5/5/2013</td>
<td>11.00</td>
<td>7.33</td>
</tr>
<tr>
<td>Project 3</td>
<td>1/30/2013</td>
<td>6/23/2013</td>
<td>6/21/2013</td>
<td>2.00</td>
<td>1.39</td>
</tr>
<tr>
<td>Project 4</td>
<td>2/18/2013</td>
<td>7/22/2013</td>
<td>8/18/2013</td>
<td>27.00</td>
<td>17.53</td>
</tr>
<tr>
<td>Project 5</td>
<td>3/4/2013</td>
<td>7/16/2013</td>
<td>7/23/2013</td>
<td>7.00</td>
<td>5.22</td>
</tr>
<tr>
<td>Project 6</td>
<td>4/16/2013</td>
<td>9/17/2013</td>
<td>9/9/2013</td>
<td>8.00</td>
<td>5.19</td>
</tr>
<tr>
<td>Project 7</td>
<td>7/16/2013</td>
<td>10/28/2013</td>
<td>11/10/2013</td>
<td>13.00</td>
<td>12.50</td>
</tr>
</tbody>
</table>

Table 17: ADIT validation data

On the basis of the results obtained during the validation process (Appendix) we are 95% confident that under repeated sampling the ADIT tool can estimate the completion time of a project with mean deviation between 2.51% and 12.75% with a margin of error of 5.54%.
In most cases, but not all, ADIT overestimates the Finish Date. This is because ADIT, with its capability to predict the impact of delayed components on the overall assembly time provides the opportunity for expeditors to expedite the supply of high impact components. This helps in reducing assembly time and resulting in the assembly operations being completed ahead of the ADIT predicted Finish Date. The ADIT tool would get more accurate as more projects are executed with the help of this tool and the standard operation times and precedence constraints are updated to replicate the actual Stack assembly scenarios.
Chapter 6

Conclusion and future work

This thesis is based on the project executed for an oil-field equipment manufacturer, with a custom engineered product portfolio. The objective of the project is to reduce the overall lead time for manufacturing and assembly of Stack Pads. The focus of this thesis is to clearly understand the capabilities of existing process improvement techniques and its practical application in a custom engineered manufacturing environment.

Some of the popular process improvement techniques such as Lean Manufacturing, Theory of Constraints and Quick Response Manufacturing were studied. It was found that although Lean and TOC cannot be directly implemented in a custom engineered manufacturing environment, many of the tools offered by these concepts could be customized to improve key performance parameters. Among all the process improvement techniques studied QRM was found to a better fit for a MTO or custom engineered manufacturing environment. However this technique is relatively new, hence requires an in depth review of the challenges in its practical application. The study of the existing manufacturing strategies available highlighted the lack of “one size fit all” strategies, and the need for customized tools that could be applied in a custom engineered manufacturing environment.

An initial analysis was conducted to understand the SBOP manufacturing and assembly process. This analysis was used to build detailed process flow maps and to identify key departments and stakeholders involved in the Stack Pad assembly process. This data driven analysis highlighted the need to focus simultaneously on the upstream preassembly and downstream assembly process. Further analysis of the downstream process helped to identify the pre assembly delays as the cause for long assembly lead times. Downstream analysis also showed that under an ideal assembly scenario without delays, the existing labor utilization and pad capacity was sufficient to meet the annual throughput targets. From the preliminary analysis, waiting for late
components and upstream delays were identified as the primary reasons for long assembly lead times. This preliminary analysis confirmed the need to focus on the stack pad assembly process and the need to develop tools to reduce the assembly delays and hence the lead time. The focus on tools that can reduce assembly delays serves two main purposes. First and foremost it will have a direct impact in reducing the assembly lead-time and at the same time it would also provide quick tangible results, which are necessary to garner support from the various stakeholders for long term, higher impact assembly delay reduction projects.

The preliminary analysis highlighted the need for tools which could be used across any stack pad project. In order to develop and implement any process improvement tools, it is necessary to have a standardized assembly analysis system in place. A standardized system provides the means to compare the existing system to an ideal system and thereby identify opportunities for improvement. Prior to this work the Stack Pad assembly did not adhere to any standardized system and hence the processes varied from project to project. There was also lack of a formal system for communicating and troubleshooting assembly issues, and recording them for future reference. This resulted in the recurrence of similar issues and assembly delays. In order to resolve this, a Delay Log sheet was developed and incorporated into the company’s online system, providing a formal tool to systematically record delays. The Delay Log ensured better accountability with regards to resolving assembly delays. It also provided the necessary data required to perform assembly delay root cause analyses. Analysis of data obtained through the delay log sheet confirmed Engineering to be the major cause of assembly delays.

In order to provide more visibility to stack pad personnel, regarding the status of a stack assembly project at any given time, and to gauge the impact of upstream delays on project completion dates, the Assembly Delay Impact Tool was created. The ADIT is a planning and scheduling tool that considers the upstream and downstream delays while generating a dynamic stack pad assembly schedule for an individual configurable stack assembly. The ADIT was implemented in the stack assembly
project. It was found that the ADIT predicted the project completion time with mean percentage deviation of 7.63% at a 95% confidence interval. The ADIT also offers several non-tangible advantages such as providing a standardized system to communicate the status of the project, offering better leverage for expeditors to expedite component delivery for assembly, helping estimate accurate delivery dates for component arrival and helping to identify late components across projects.

The ADIT has been programmed in Excel VBA because of the ease of using Excel and the user friendly options built into it. The ADIT could be built using a more robust programming language so that it could be made consistent with the existing NOV online tools and databases, available globally. The ADIT could be extended to include the upstream process thereby improving the forecasting capability of the tool. The ADIT could also be integrated to the Kronos and Glovia system to minimize manual data entry and to automate the system. The ADIT is currently designed such that the shift duration and the number of working days per week must be assigned at the beginning of the project. These values cannot be modified once specified. However in the real project scenario, these two parameters are variables, possibly allowing the user to modify the value in the tool would help to improve the accuracy of the estimated project completion date.

The work in this thesis focuses on standardizing the operations on the downstream side and reducing assembly delays, in order to reduce the stack pad assembly lead time. As seen during the ADIT validation stage adopting the best practices from similar projects could also help to further improve estimates of standard assembly operation times. Therefore continued analysis can capture the best practices from each project and apply them to future projects.

The initiatives undertaken in this work and the significant results obtained, represent only a small portion of the improvements possible. The preliminary studies and root cause analysis have shown the upstream delays to be the major contributor to the
overall assembly lead time. The improvements made on the upstream side can be expected to have a larger impact in reducing assembly delays and the overall lead time. The logical extension of this work would be to include the Engineering and Manufacturing department in the process improvement initiatives. A detailed analysis of the Engineering and Manufacturing processes and identification of the bottlenecks in each department should be the focus of the next study. Developing a real time tracking system based on RFID, which could track the status of each component required for the stack assembly, could help to plan and schedule the stack assembly project more accurately on a real time basis. This would also help in identifying the bottle necks in each department and would support in the buy/make decisions of the Supply Chain department.
Bibliography

Singh V. P. (2012) Framework to Implement Lean in Low Volume High Mix Manufacturing Units


# APPENDICES

**Appendix A** – Standardized configurable stack operation sequence and time, for the LWR Stack, LMRP and Testing & Tear Down.

<table>
<thead>
<tr>
<th>ID</th>
<th>OP #</th>
<th>Task Name</th>
<th>Predecessors</th>
<th>Standard Assembly Duration</th>
<th>Standard Assembly Hours</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>200</td>
<td>TEST STUMP, LWR SPIDER, LWR BOP</td>
<td></td>
<td>0.5 days</td>
<td>48</td>
</tr>
<tr>
<td>7</td>
<td>300</td>
<td>LWR BOP DUAL VALVES</td>
<td>3</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>8</td>
<td>400</td>
<td>LOWER MINI SPIDER, UPPER BOP</td>
<td>3</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>12</td>
<td>500</td>
<td>UPPER BOP DUAL VALVES</td>
<td></td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>13</td>
<td>600</td>
<td>UPR MINI SPIDER, SPACER SPOOL/SINGLE BOP</td>
<td>8</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>17</td>
<td>700</td>
<td>UPPER SPIDER</td>
<td>13</td>
<td>0.63 days</td>
<td>60</td>
</tr>
<tr>
<td>28</td>
<td>800</td>
<td>4 LEGS</td>
<td>17</td>
<td>0.42 days</td>
<td>40</td>
</tr>
<tr>
<td>37</td>
<td>900</td>
<td>ATTACH MINI SPIDER TO LEGS</td>
<td>28</td>
<td>0.55 days</td>
<td>40</td>
</tr>
<tr>
<td>44</td>
<td>1000</td>
<td>DCB BOTTLES AND PISTON BOTTLES</td>
<td>37</td>
<td>30 hrs</td>
<td>120</td>
</tr>
<tr>
<td>45</td>
<td>1100</td>
<td>HYDROPHONIC PODS AND ARMS</td>
<td>37</td>
<td>13.3 hrs</td>
<td>40</td>
</tr>
<tr>
<td>46</td>
<td>1200</td>
<td>BARRIER BOTTLE RACKS</td>
<td>37</td>
<td>26.7 hrs</td>
<td>80</td>
</tr>
<tr>
<td>47</td>
<td>1300</td>
<td>FIT ACOUSTIC POD</td>
<td>3</td>
<td>2 hrs</td>
<td>4</td>
</tr>
<tr>
<td>48</td>
<td>1400</td>
<td>INSTALL TRAP DOOR AND LADDER</td>
<td>37</td>
<td>20 hrs</td>
<td>40</td>
</tr>
<tr>
<td>49</td>
<td>1500</td>
<td>INSTALL ACOUSTIC POD 1st TIME</td>
<td>47,48</td>
<td>1.3 hrs</td>
<td>4</td>
</tr>
<tr>
<td>50</td>
<td>1600</td>
<td>FABRICATE SHUTTLE VALVE TREES (LWR STK)</td>
<td>8</td>
<td>35 hrs</td>
<td>140</td>
</tr>
<tr>
<td>51</td>
<td>1700</td>
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<tr>
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<tr>
<td>94</td>
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<td>94</td>
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<td>119</td>
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<tr>
<td>127</td>
<td>4400</td>
<td>PODS, POD BOWLS, STABS AND SPLS</td>
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<tr>
<td>133</td>
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<tr>
<td>134</td>
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<td>REMOVE POD BOWLS, DRILL HOSES</td>
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<td>REINSTALL POD BOWLS AND SECONDARIES</td>
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<td>144</td>
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<td>145</td>
<td>5500</td>
<td>INSTALL HOSES LWR STK</td>
<td>135,138,141,144</td>
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<td>5600</td>
<td>CHARGE DCB BOTTLES AND AC. BOTTLES</td>
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<td>ANODES/END</td>
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**LWR STACK**

26.5 days 3872
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<td>151</td>
<td>400</td>
<td>LMRP LEGS, TRUSSES, COMP. BEAMS AND BRACES</td>
<td>149,150,152</td>
<td>37.5 hrs</td>
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<tr>
<td>152</td>
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<td>ALIGN AND TORQUE SBOP TO CONNECTOR</td>
<td>149,150,152</td>
<td>21.3 hrs</td>
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<tr>
<td>153</td>
<td>600</td>
<td>ALIGN AND TORQUE SBOP AND CONNECTOR TO LMRP</td>
<td>149,150,152</td>
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<tr>
<td>154</td>
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<td>LAND 2ND SBOP ON 1ST SBOP (if two SBOPs)</td>
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<td>155</td>
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<td>INSTALL BLIND FLANGES ON SBOP</td>
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<td>177</td>
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<td>179</td>
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LMRP 40.68 days 2292
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<td>200</td>
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<td>208</td>
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<td>210</td>
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<td>FINAL VISUAL QC INSPECTION</td>
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**TESTING AND TEAR DOWN**

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Appendix B.1 – The ADIT Excel VBA code

Module 1

Sub Start_Date()

Application.ScreenUpdating = False
Worksheets("Sequence&Labor").Protect
Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("wo_delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("part").Protect
Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("critical_paths").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Sheets("delays_hrs").Visible = True
Sheets("wo_delays_hrs").Visible = True
Sheets("Sequence&Labor").Select
ProjUserForm.Show
StartDateUserform.Show
ShiftUserform.Show
Sheets("delays_hrs").Visible = False
Sheets("wo_delays_hrs").Visible = False
Sheets("wo_delays_hrs").Visible = False
Application.ScreenUpdating = True

End Sub

Sub Critical_Path()

Worksheets("Sequence&Labor").Protect
Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("delays_hrs").Protect
Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("wo_delays_hrs").Protect
Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("part").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("critical_paths").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Application.ScreenUpdating = False
Sheets("delays_hrs").Visible = True
Sheets("wo_delays_hrs").Visible = True
Sheets("part").Visible = True
Sheets("delays_hrs").Select
Dim rowcount As Integer
Dim colcount As Integer
Dim row As Integer
Dim col As Integer
Dim cformatsize As Integer
Dim row1 As Integer
Dim id As Integer

Range("B5:AG158").Select

With Selection.Interior
    .Pattern = xlNone
    .TintAndShade = 0
    .PatternTintAndShade = 0
End With

'FOR LWR STACK

For rowcount = 1 To 7
    For colcount = 1 To 7
        If (WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 2, colcount * 4).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 3, colcount * 4).Value, 0)) Then
            Sheets("delays_hrs").Cells((rowcount * 3) + 2, (colcount * 4) - 1).Select
            With Selection.Interior
                .Pattern = xlSolid
                .PatternColorIndex = xlAutomatic
                .Color = 65535
                .TintAndShade = 0
                .PatternTintAndShade = 0
            End With
        End If
    Next colcount
Next rowcount

    Sheets("delays_hrs").Cells(26, 27).Select
    With Selection.Interior
        .Pattern = xlSolid
        .PatternColorIndex = xlAutomatic
        .Color = 65535
        .TintAndShade = 0
        .PatternTintAndShade = 0
    End With
End If
If (WorksheetFunction.Round(Sheets("delays_hrs").Cells(26, 28).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs").Cells(27, 28).Value, 0)) Then
    Sheets("delays_hrs").Cells(26, 27).Select
    With Selection.Interior
        .Pattern = xlSolid
        .PatternColorIndex = xlAutomatic
        .Color = 65535
        .TintAndShade = 0
        .PatternTintAndShade = 0
    End With
End If

' FOR LMRP

For rowcount = 1 To 7
    For colcount = 1 To 5
        If (WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 54, colcount * 4).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs"),Cells((rowcount * 3) + 55, colcount * 4).Value, 0)) Then
            Sheets("delays_hrs"),Cells((rowcount * 3) + 54, (colcount * 4) - 1).Select
            With Selection.Interior
                .Pattern = xlSolid
                .PatternColorIndex = xlAutomatic
                .Color = 65535
                .TintAndShade = 0
                .PatternTintAndShade = 0
            End With
        End If
    Next colcount
Next rowcount

For rowcount = 1 To 3
    If (WorksheetFunction.Round(Sheets("delays_hrs"),Cells((rowcount * 3) + 54, 24).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs"),Cells((rowcount * 3) + 55, 24).Value, 0)) Then
        Sheets("delays_hrs"),Cells((rowcount * 3) + 54, 23).Select
        With Selection.Interior
            .Pattern = xlSolid
            .PatternColorIndex = xlAutomatic
            .Color = 65535
        End With
    End If
.TintAndShade = 0
.PatternTintAndShade = 0
End With
End If

Next rowcount

' FOR TTD

For rowcount = 1 To 7

    If (WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 101, 4).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 102, 4).Value, 0)) Then
        Sheets("delays_hrs").Cells((rowcount * 3) + 101, 3).Select
        With Selection.Interior
            .Pattern = xlSolid
            .PatternColorIndex = xlAutomatic
            .Color = 65535
            .TintAndShade = 0
            .PatternTintAndShade = 0
        End With
    End If

Next rowcount

For rowcount = 1 To 2

    If (WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 101, 8).Value, 0) = WorksheetFunction.Round(Sheets("delays_hrs").Cells((rowcount * 3) + 102, 8).Value, 0)) Then
        Sheets("delays_hrs").Cells((rowcount * 3) + 101, 7).Select
        With Selection.Interior
            .Pattern = xlSolid
            .PatternColorIndex = xlAutomatic
            .Color = 65535
            .TintAndShade = 0
            .PatternTintAndShade = 0
        End With
    End If

Next rowcount
DISPLAYING CRITICAL PATH IN THE SEQUENCE&LABOR SHEET

Sheets("Sequence&Labor").Select

Range("B5:M104").Select 'changing existing color
With Selection.Interior
  .Pattern = xlNone
  .TintAndShade = 0
  .PatternTintAndShade = 0
End With

Range("BB5:BB104").Select removing the data used in if statement for graphics
Selection.ClearContents
Range("B5").Select

For row = 5 To 123
For col = 3 To 27

  If (Sheets("delays_hrs").Cells(row, col).Interior.Color = 65535) Then

    id = Sheets("delays_hrs").Cells(row, col).Value

    For row1 = 5 To 104

      If (id = Sheets("Sequence&Labor").Cells(row1, 2).Value) Then

        Sheets("Sequence&Labor").Cells(row1, 2).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 3).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 4).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 5).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 6).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 8).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 9).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 11).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 12).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 13).Interior.Color = 65535
        Sheets("Sequence&Labor").Cells(row1, 54).Value = 1

      End If

    Next row1

    End If

  End If

Next row
End If
Next col
Next row

' ENTERS THE CRITICAL PATH IN THE critical_path SHEET
Dim colorcounter As Integer
Dim operationcounter As Integer
Dim therange As Range
Dim rowsize As Integer
pathcounter = Sheets("Sequence&Labor").Cells(6, 53).Value  '***

Sheets("critical_paths").Select
Range("A1").UnMerge
Range("A1").Select
Sheets("critical_paths").Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(1, pathcounter)).Merge
ActiveCell.Value = "CRITICAL PATHS"
With Selection
  .HorizontalAlignment = xlCenter
  .VerticalAlignment = xlCenter
End With
Sheets("critical_paths").Cells(3, pathcounter).Select
Sheets("critical_paths").Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(0, 1)).Merge
ActiveCell.Value = Sheets("Sequence&Labor").Cells(26, 18).Value
With Selection
  .HorizontalAlignment = xlCenter
  .VerticalAlignment = xlCenter
End With
Sheets("critical_paths").Cells(4, pathcounter).Value = "ID"
Sheets("critical_paths").Cells(4, pathcounter).Select
With Selection
  .HorizontalAlignment = xlCenter
  .VerticalAlignment = xlCenter
End With
Sheets("critical_paths").Cells(4, pathcounter + 1).Value = "OP#"
Sheets("critical_paths").Cells(4, pathcounter + 1).Select
With Selection
  .HorizontalAlignment = xlCenter
  .VerticalAlignment = xlCenter
End With
Columns(pathcounter + 1).ColumnWidth = 30
Sheets("Sequence&Labor").Select
operationcounter = 5

For colorcounter = 5 To 104

    If (Cells(colorcounter, 3).Interior.Color = 65535) Then

        Sheets("critical_paths").Cells(operationcounter, pathcounter).Value = Cells(colorcounter, 2).Value

        Sheets("critical_paths").Cells(operationcounter, pathcounter).HorizontalAlignment = xlCenter
        Sheets("critical_paths").Cells(operationcounter, pathcounter).VerticalAlignment = xlCenter

        Sheets("critical_paths").Cells(operationcounter, pathcounter + 1).Value = Cells(colorcounter, 3).Value

        Sheets("critical_paths").Cells(operationcounter, pathcounter + 1).HorizontalAlignment = xlLeft
        Sheets("critical_paths").Cells(operationcounter, pathcounter + 1).VerticalAlignment = xlCenter

            With Selection
                .HorizontalAlignment = xlLeft
                .VerticalAlignment = xlCenter
            End With

        operationcounter = operationcounter + 1

    End If

Next

cformatsize = Application.WorksheetFunction.CountA(Worksheets("critical_paths").Columns((pathcounter)))

Sheets("critical_paths").Select
Cells(4, pathcounter).Select
Range(ActiveCell.Offset(0, 0), ActiveCell.Offset((cformatsize - 2), 1)).Select

Selection.Borders(xlInsideVertical).Weight = xlThin
Selection.Borders(xlInsideHorizontal).Weight = xlThin
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(1, 1).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(3, pathcounter + 1).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(4, pathcounter).Select
Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(0, 1)).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

pathcounter = pathcounter + 2
Sheets("Sequence&Labor").Cells(6, 53).Value = pathcounter  '***

Sheets("Sequence&Labor").Select

Sheets("delays_hrs").Visible = False
Sheets("wo_delays_hrs").Visible = False
Sheets("part").Visible = False

Application.ScreenUpdating = True
'Cells(5, 2).Select

End Sub
Module 2

Global operation As Integer
Global oprtname As String
Global delayoption As Integer
Global size As Integer
Global assycount As Integer ' Used in AssyUserForm
Global pathcounter As Integer ' Used in module1
Global delaypathcounter As Integer ' Used in module3

Sub delay()

Worksheets("Sequence&Labor").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("wo_delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("part").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Worksheets("critical_paths").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Application.ScreenUpdating = False
Sheets("delays_hrs").Visible = True
Sheets("wo_delays_hrs").Visible = True
Sheets("part").Visible = True
Sheets("Sequence&Labor").Select
delayUserForm.Show
Sheets("delays_hrs").Visible = False
Sheets("wo_delays_hrs").Visible = False
Sheets("part").Visible = False
Application.ScreenUpdating = True

End Sub
Module 3

Sub delay_report()  ' ENTERS THE DELAY REPORT IN THE delay_report SHEET

Dim optno As Integer
Dim optprtsize As Integer
Dim optprt As Integer
Dim operationcounter As Integer
Dim therange As Range
Dim rowsize As Integer
Dim delayassycount As Integer
Dim formatsize As Integer

Worksheets("Sequence&Labor").Protect Password:="novms", UserInterfaceOnly:=True  'Protects the work sheet
Worksheets("delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True  'Protects the work sheet
Worksheets("wo_delays_hrs").Protect Password:="novms", UserInterfaceOnly:=True  'Protects the work sheet
Worksheets("part").Protect Password:="novms", UserInterfaceOnly:=True  'Protects the work sheet
Worksheets("critical_paths").Protect Password:="novms", UserInterfaceOnly:=True  'Protects the work sheet

Application.ScreenUpdating = False
Sheets("delays_hrs").Visible = True
Sheets("wo_delays_hrs").Visible = True
Sheets("part").Visible = True
delaypathcounter = Sheets("Sequence&Labor").Cells(7, 53).Value
Sheets("delay_report").Select
Range("A1").UnMerge
Range("A1").Select
Sheets("delay_report").Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(1, delaypathcounter + 2)).Merge
ActiveCell.Value = "DELAY REPORT"
With Selection
  .HorizontalAlignment = xlCenter
  .VerticalAlignment = xlCenter
End With

Sheets("delay_report").Cells(3, delaypathcounter).Select
Sheets("delay_report").Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(0, 3)).Merge
ActiveCell.Value = Sheets("Sequence&Labor").Cells(26, 18).Value
With Selection
.HorizontalAlignment = xlCenter
.VerticalAlignment = xlCenter
End With

Sheets("delay_report").Cells(4, delaypathcounter).Value = "OPT #"
Sheets("delay_report").Cells(4, delaypathcounter).Select
With Selection
 .HorizontalAlignment = xlCenter
 .VerticalAlignment = xlCenter
End With

Sheets("delay_report").Cells(4, delaypathcounter + 1).Value = "PART"
Sheets("delay_report").Cells(4, delaypathcounter + 1).Select
With Selection
 .HorizontalAlignment = xlCenter
 .VerticalAlignment = xlCenter
End With

Sheets("delay_report").Cells(4, delaypathcounter + 2).Value = "S/F DATE"
Sheets("delay_report").Cells(4, delaypathcounter + 2).Select
With Selection
 .HorizontalAlignment = xlCenter
 .VerticalAlignment = xlCenter
End With

Sheets("delay_report").Cells(4, delaypathcounter + 3).Value = "COMMENTS"
Sheets("delay_report").Cells(4, delaypathcounter + 3).Select
With Selection
 .HorizontalAlignment = xlCenter
 .VerticalAlignment = xlCenter
End With

Columns(delaypathcounter).ColumnWidth = 30
Columns(delaypathcounter + 1).ColumnWidth = 30
Columns(delaypathcounter + 2).ColumnWidth = 15
Columns(delaypathcounter + 3).ColumnWidth = 45

Sheets("Sequence&Labor").Select

operationcounter = 5

For optno = 1 To 98

optprtsize = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(((2 * optno) - 1))) - 7)
For optprt = 5 To (5 + optprtsize - 1)

If (Sheets("part").Cells(optprt, (2 * optno)).Value <> "N/A") Then 'for all the parts

Sheets("delay_report").Cells(operationcounter, delaypathcounter).Value =
Sheets("part").Cells(1, (2 * optno) - 1).Value

Sheets("delay_report").Cells(operationcounter, delaypathcounter).HorizontalAlignment =
xlCenter
Sheets("delay_report").Cells(operationcounter, delaypathcounter).VerticalAlignment =
xlCenter

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).Value =
Sheets("part").Cells(optprt, (2 * optno) - 1).Value

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).HorizontalAlignment =
xlCenter
Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).VerticalAlignment =
xlCenter

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).Value =
VBA.Format(Sheets("part").Cells(optprt, 2 * optno).Value, "d mmm yy")

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).HorizontalAlignment =
xLeft
Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).VerticalAlignment =
xlCenter

operationcounter = operationcounter + 1
End If

Next optprt
delayassycount = 0

Do

delayassycount = delayassycount + 1

Loop Until (Sheets("part").Cells(delayassycount, (2 * optno) - 1).Value) = "Assy. delay"
'counts the row which has assy delay date in "part" sheet

If (Sheets("part").Cells(delayassycount, (2 * optno)).Value <> "N/A") Then

Sheets("delay_report").Cells(operationcounter, delaypathcounter).Value =
Sheets("part").Cells(1, (2 * optno) - 1).Value

End If

Next delayassycount
Sheets("delay_report").Cells(operationcounter, delaypathcounter).HorizontalAlignment = xlCenter
Sheets("delay_report").Cells(operationcounter, delaypathcounter).VerticalAlignment = xlCenter

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).Value =
Sheets("part").Cells(delayassycount, (2 * optno) - 1).Value

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).HorizontalAlignment = xlCenter
Sheets("delay_report").Cells(operationcounter, delaypathcounter + 1).VerticalAlignment = xlCenter

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).Value =
VBA.Format(Sheets("part").Cells(delayassycount, 2 * optno).Value, "d mmm yy")

Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).HorizontalAlignment = xLeft
Sheets("delay_report").Cells(operationcounter, delaypathcounter + 2).VerticalAlignment = xlCenter

operationcounter = operationcounter + 1
End If

Next optno

formatsize =

Sheets("delay_report").Select
Cells(4, delaypathcounter).Select
Range(ActiveCell.Offset(0, 0), ActiveCell.Offset((formatsize - 2), 2)).Select

Selection.Borders(xlInsideVertical).Weight = xlThin
Selection.Borders(xlInsideHorizontal).Weight = xlThin

Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(1, 1).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(3, delaypathcounter + 1).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

Cells(4, delaypathcounter).Select
Range(ActiveCell.Offset(0, 0), ActiveCell.Offset(0, 2)).Select
Selection.Borders(xlEdgeLeft).Weight = xlMedium
Selection.Borders(xlEdgeTop).Weight = xlMedium
Selection.Borders(xlEdgeBottom).Weight = xlMedium
Selection.Borders(xlEdgeRight).Weight = xlMedium

delaypathcounter = delaypathcounter + 3
Sheets("Sequence&Labor").Cells(7, 53).Value = delaypathcounter  ***

Sheets("Sequence&Labor").Select

Sheets("delays_hrs").Visible = False
Sheets("wo_delays_hrs").Visible = False
Sheets("part").Visible = False

Application.ScreenUpdating = True

End Sub
Module 4

Dim mColButtons As New Collection
Dim mColButtons1 As New Collection

Sub addLabelnew(operation)

UserForm.Show vbModeless
Dim theLabel As Object

Dim theList1 As Object
Dim theList2 As Object
Dim theList3 As Object
Dim labelCounter As Long
Dim thecommandbutton1(15) As Object
Dim thecommandbutton2 As Object
Dim thedtpicker1 As Object

Dim btnEvent(15) As clstest
Dim btn1event As clsok

size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(((2 * operation) - 1)))) - 7

With UserForm
    .Caption = "Part list " & oprtname
    .Height = (30 * (size + 1)) + 55
    .Width = 400
End With

For labelCounter = 1 To size

    Set theLabel = UserForm.Controls.Add("Forms.Label.1", True)
    With theLabel
        .Caption = Sheets("part").Cells(labelCounter + 4, ((2 * operation) - 1)).Value & vbLf & "( & VBA.Format(Sheets("part").Cells(labelCounter + 4, (2 * operation)).Value, "d mmm yy") & ")"
        .Left = 10
        .Width = 175
        .Top = 30 * labelCounter
        .Height = 20
    End With

End For
Set thecommandbutton1(labelCounter) = UserForm.Controls.Add("Forms.CommandButton.1", True)

    With thecommandbutton1(labelCounter)
        .Caption = "Enter Arrival Date"
        .Left = 200
        .Width = 100
        .Top = 30 * labelCounter
        .Height = 20
        .Name = labelCounter
    End With

'CREATE EVENT PROCEDURE FOR DYNAMIC CONTROL BUTTON

    Set btnEvent(labelCounter) = New clstest
    Set btnEvent(labelCounter).btn = thecommandbutton1(labelCounter)
    Set btnEvent(labelCounter).frm = UserForm
    mColButtons.Add btnEvent(labelCounter)

Next labelCounter

    Set thecommandbutton2 = UserForm.Controls.Add("Forms.CommandButton.1", True)
    With thecommandbutton2
        .Caption = "OK"
        .Left = 325
        .Width = 50
        .Top = (30 * labelCounter) / 2
        .Height = 20
    End With

    Set btn1event = New clsok
    Set btn1event.btn1 = thecommandbutton2
    Set btn1event.frm = UserForm
    mColButtons1.Add btn1event

End Sub
Module 5

Sub similar_operation()

    Dim op200counter As Integer
    Dim op200size As Integer
    Dim op300counter As Integer
    Dim op300size As Integer
    Dim rowloc200 As Integer
    Dim rowloc300 As Integer
    Dim max23 As String
    Dim op400counter As Integer
    Dim op400size As Integer
    Dim op500counter As Integer
    Dim op500size As Integer
    Dim rowloc400 As Integer
    Dim rowloc500 As Integer
    Dim max45 As String

' CHECKS OPERATION 200 & 300 FOR THE PART "LWR BOP (LWR TRIPLE)"
DATES AND UPDATES BOTH WITH THE SAME MAX DATE
max23 = "N/A"

    op200size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(1)))
                - 7 ' finds column size of op 200

    For op200counter = 1 To op200size
        If (Worksheets("part").Cells(4 + op200counter, 1).Value = "LWR BOP (LWR TRIPLE)") Then
            rowloc200 = 4 + op200counter
            MsgBox "row location of op200" & rowloc200
        End If
    Next op200counter

    If (Worksheets("part").Cells(rowloc200, 2).Value <> "N/A") Then
        max23 = Worksheets("part").Cells(rowloc200, 2).Value
    End If

    op300size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(3)))
                - 7 ' finds column size of op 300
For op300counter = 1 To op300size
If (Worksheets("part").Cells(4 + op300counter, 3).Value = "LWR BOP (LWR TRIPLE)") Then ' finds location of "LWR BOP (LWR TRIPLE)"
rowloc300 = 4 + op300counter
MsgBox "row location of op300" & rowloc300
End If
Next op300counter

If (Worksheets("part").Cells(rowloc300, 4).Value <> "N/A") Then
  If (max23 <> "N/A") Then
    If (Worksheets("part").Cells(rowloc300, 4).Value >= max23) Then
      max23 = Worksheet
      max23 = Worksheet("part").Cells(rowloc300, 4).Value         'Assigns the date of op300
      max23 = Worksheet("part").Cells(rowloc300, 4).Value         'Assigns the date of op300
      max23 = Worksheet("part").Cells(rowloc300, 4).Value         'Assigns the date of op300
    End If
  ElseIf (max23 = "N/A") Then
    max23 = Worksheet("part").Cells(rowloc300, 4).Value              'Assigns the date of
    max23 = Worksheet("part").Cells(rowloc300, 4).Value              'Assigns the date of
    max23 = Worksheet("part").Cells(rowloc300, 4).Value              'Assigns the date of
  End If
End If

Worksheets("part").Cells(rowloc200, 2).Value = max23            'Updates the date value as max
Worksheets("part").Cells(rowloc300, 4).Value = max23            'Updates the date value as max

' CHECKS OPERATION 400 & 500 FOR THE PART "UPPER BOP (UPR TRIPLE)"
DATES AND UPDATES BOTH WITH THE SAME MAX DATE
max45 = "N/A"
op400size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(5)))
  - 7    ' finds column size of op 400
For op400counter = 1 To op400size
If (Worksheets("part").Cells(4 + op400counter, 5).Value = "UPPER BOP (UPR TRIPLE)") Then ' finds location of "UPPER BOP (UPR TRIPLE)"
rowloc400 = 4 + op400counter
MsgBox "row location of op400" & rowloc400
End If
Next op400counter

If (Worksheets("part").Cells(rowloc400, 6).Value <> "N/A") Then
  max45 = Worksheet("part").Cells(rowloc400, 6).Value
  'Assigns the date of op400 to max if the date is not "N/A"
End If
op500size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(7))) - 7 ' finds column size of op 500

For op500counter = 1 To op500size
If (Worksheets("part").Cells(4 + op500counter, 7).Value = "UPPER BOP (UPR TRIPLE)") Then ' finds location of "UPPER BOP (UPR TRIPLE)"
rowloc500 = 4 + op500counter
MsgBox "row location of op500" & rowloc500
End If
Next op500counter

If (Worksheets("part").Cells(rowloc500, 8).Value <> "N/A") Then
If (max45 <> "N/A") Then
If (Worksheets("part").Cells(rowloc500, 8).Value >= max45) Then
max45 = Worksheets("part").Cells(rowloc500, 8).Value 'Assigns the date of op300 to max if the date is not "N/A" and > than op200
End If
ElseIf (max45 = "N/A") Then
max45 = Worksheets("part").Cells(rowloc500, 8).Value
'Assigns the date of op500 to max if the date is not "N/A" and > than op200
End If
End If
End If

Worksheets("part").Cells(rowloc400, 6).Value = max45 '
Updates the date value as max
Worksheets("part").Cells(rowloc500, 8).Value = max45 '
Updates the date value as max

End Sub

AssydateUserForm

Private Sub CommandButton1_Click()

'Dim count As Integer
'Dim size As Integer
'size = (Application.WorksheetFunction.CountA(Worksheets("part").Columns(((2 * operation) - 1))))
'Sheets("part").Cells((size - 2), (2 * operation)).Value = DayListBox3.Value + 1 & monthListBox3.Value & YearListBox3.Value 'daylistbox.value needs to be added by 1 to get right value
Sheets("part").Cells(assycount, (2 * operation)).Value = DayListBox3.Value + 1 & monthListBox3.Value & YearListBox3.Value 'daylistbox.value needs to be added by 1 to get right value
Unload AssydateUserForm
'Call delay_calc
End Sub

Private Sub CommandButton2_Click()
Unload AssydateUserForm
End Sub

Private Sub ListBox1_Click()
End Sub

Private Sub UserForm_Initialize()

Dim dates As String
With monthListBox3
  .AddItem "January"
  .AddItem "February"
  .AddItem "March"
  .AddItem "April"
  .AddItem "May"
  .AddItem "June"
  .AddItem "July"
  .AddItem "August"
  .AddItem "September"
  .AddItem "October"
  .AddItem "November"
  .AddItem "December"
End With
AssydateUserForm.monthListBox3.Selected(0) = True
With DayListBox3
  .AddItem "01"
  .AddItem "02"
  .AddItem "03"
  .AddItem "04"
  .AddItem "05"
  .AddItem "06"
  .AddItem "07"
  .AddItem "08"
  .AddItem "09"
  .AddItem "10"
  .AddItem "11"
  .AddItem "12"
  .AddItem "13"
  .AddItem "14"
  .AddItem "15"
  .AddItem "16"
  .AddItem "17"
End With


With AssydateUserForm.DayListBox3
    DayListBox3.Selected(0) = True
End With

With AssydateUserForm.YearListBox3
    YearListBox3.Selected(0) = True
End With

'Select the first list item
monthListBox3.ListIndex = 0
DayListBox3.ListIndex = 0
YearListBox3.ListIndex = 0

End Sub

Private Sub YearListBox3_Click()

End Sub

AssyUserForm

Private Sub CommandButton1_Click()
AssydateUserForm.Show
End Sub

Private Sub CommandButton2_Click()
Unload AssyUserForm
Call delay_report
Call Critical_Path
End Sub

Private Sub UserForm_Initialize()
assycount = 0
Do
assycount = assycount + 1
Loop Until (Sheets("part").Cells(assycount, (2 * operation) - 1).Value) = "Assy. delay"
'counts the row which has assy delay date in "part" sheet

With AssyUserForm
    .Caption = "Assy Delay " & oprtname
End With
With assydelayLabel
    .Caption = "Assembly Delay" & vbLf & "(" & VBA.Format(Sheets("part").Cells(assycount, (2 * operation)).Value, "d mmm yy") & ")"
End With

End Sub

delayUserForm

Private Sub CommandButton1_Click()
Select Case delayListBox.Value
Case "LWR STACK - Op# 200"
  operation = 1
  oprtname = "LWR STACK - Op# 200"
Case "LWR STACK - Op# 300"
  operation = 2
  oprtname = "LWR STACK - Op# 300"
Case "LWR STACK - Op# 400"
  operation = 3
  oprtname = "LWR STACK - Op# 400"
Case "LWR STACK - Op# 500"
  operation = 4
  oprtname = "LWR STACK - Op# 500"
Case "LWR STACK - Op# 600"
  operation = 5
  oprtname = "LWR STACK - Op# 600"
Case "LWR STACK - Op# 700"
  operation = 6
  oprtname = "LWR STACK - Op# 700"
Case "LWR STACK - Op# 800"
  operation = 7
  oprtname = "LWR STACK - Op# 800"
Case "LWR STACK - Op# 900"
  operation = 8
  oprtname = "LWR STACK - Op# 900"
Case "LWR STACK - Op# 1000"
  operation = 9
  oprtname = "LWR STACK - Op# 1000"
Case "LWR STACK - Op# 1100"
  operation = 10
  oprtname = "LWR STACK - Op# 1100"
Case "LWR STACK - Op# 1200"
  operation = 11
  oprtname = "LWR STACK - Op# 1200"
Case "LWR STACK - Op# 1300"
  operation = 12
  oprtname = "LWR STACK - Op# 1300"
Case "LWR STACK - Op# 1400"
  operation = 13
  oprtname = "LWR STACK - Op# 1400"
Case "LWR STACK - Op# 1500"
  operation = 14
  oprtname = "LWR STACK - Op# 1500"
Case "LWR STACK - Op# 1600"
  operation = 15
oprtname = "LWR STACK - Op# 1600"
Case "LWR STACK - Op# 1700"
  operation = 16
  oprtname = "LWR STACK - Op# 1700"
Case "LWR STACK - Op# 1800"
  operation = 17
  oprtname = "LWR STACK - Op# 1800"
Case "LWR STACK - Op# 1900"
  operation = 18
  oprtname = "LWR STACK - Op# 1900"
Case "LWR STACK - Op# 2000"
  operation = 19
  oprtname = "LWR STACK - Op# 2000"
Case "LWR STACK - Op# 2100"
  operation = 20
  oprtname = "LWR STACK - Op# 2100"
Case "LWR STACK - Op# 2200"
  operation = 21
  oprtname = "LWR STACK - Op# 2200"
Case "LWR STACK - Op# 2400/2500"
  operation = 22
  oprtname = "LWR STACK - Op# 2400/2500"
Case "LWR STACK - Op# 2600"
  operation = 23
  oprtname = "LWR STACK - Op# 2600"
Case "LWR STACK - Op# 2700/2800/2900/3000"
  operation = 24
  oprtname = "LWR STACK - Op# 2700/2800/2900/3000"
Case "LWR STACK - Op# 3100"
  operation = 25
  oprtname = "LWR STACK - Op# 3100"
Case "LWR STACK - Op# 3200"
  operation = 26
  oprtname = "LWR STACK - Op# 3200"
Case "LWR STACK - Op# 3300"
  operation = 27
  oprtname = "LWR STACK - Op# 3300"
Case "LWR STACK - Op# 3400"
  operation = 28
  oprtname = "LWR STACK - Op# 3400"
Case "LWR STACK - Op# 3500"
  operation = 29
  oprtname = "LWR STACK - Op# 3500"
Case "LWR STACK - Op# 3600"
  operation = 30
  oprtname = "LWR STACK - Op# 3600"
Case "LWR STACK - Op# 3700"
    operation = 31
    oprtname = "LWR STACK - Op# 3700"
Case "LWR STACK - Op# 3800"
    operation = 32
    oprtname = "LWR STACK - Op# 3800"
Case "LWR STACK - Op# 3900"
    operation = 33
    oprtname = "LWR STACK - Op# 3900"
Case "LWR STACK - Op# 4000"
    operation = 34
    oprtname = "LWR STACK - Op# 4000"
Case "LWR STACK - Op# 4100"
    operation = 35
    oprtname = "LWR STACK - Op# 4100"
Case "LWR STACK - Op# 4200"
    operation = 36
    oprtname = "LWR STACK - Op# 4200"
Case "LWR STACK - Op# 4300"
    operation = 37
    oprtname = "LWR STACK - Op# 4300"
Case "LWR STACK - Op# 4400"
    operation = 38
    oprtname = "LWR STACK - Op# 4400"
Case "LWR STACK - Op# 4500"
    operation = 39
    oprtname = "LWR STACK - Op# 4500"
Case "LWR STACK - Op# 4600"
    operation = 40
    oprtname = "LWR STACK - Op# 4600"
Case "LWR STACK - Op# 4700"
    operation = 41
    oprtname = "LWR STACK - Op# 4700"
Case "LWR STACK - Op# 4800"
    operation = 42
    oprtname = "LWR STACK - Op# 4800"
Case "LWR STACK - Op# 4900"
    operation = 43
    oprtname = "LWR STACK - Op# 4900"
Case "LWR STACK - Op# 5000"
    operation = 44
    oprtname = "LWR STACK - Op# 5000"
Case "LWR STACK - Op# 5100"
    operation = 45
    oprtname = "LWR STACK - Op# 5100"
Case "LWR STACK - Op# 5200"
operation = 46
oprtname = "LWR STACK - Op# 5200"

Case "LWR STACK - Op# 5300"
operation = 47
oprtname = "LWR STACK - Op# 5300"

Case "LWR STACK - Op# 5400"
operation = 48
oprtname = "LWR STACK - Op# 5400"

Case "LWR STACK - Op# 5500"
operation = 49
oprtname = "LWR STACK - Op# 5500"

Case "LWR STACK - Op# 5600"
operation = 50
oprtname = "LWR STACK - Op# 5600"

Case "LWR STACK - Op# 5700"
operation = 51
oprtname = "LWR STACK - Op# 5700"

Case "LMRP - Op# 200"
operation = 52
oprtname = "LMRP - Op# 200"

Case "LMRP - Op# 300"
operation = 53
oprtname = "LMRP - Op# 300"

Case "LMRP - Op# 400"
operation = 54
oprtname = "LMRP - Op# 400"

Case "LMRP - Op# 500"
operation = 55
oprtname = "LMRP - Op# 500"

Case "LMRP - Op# 600"
operation = 56
oprtname = "LMRP - Op# 600"

Case "LMRP - Op# 700"
operation = 57
oprtname = "LMRP - Op# 700"

Case "LMRP - Op# 800"
operation = 58
oprtname = "LMRP - Op# 800"

Case "LMRP - Op# 900"
operation = 59
oprtname = "LMRP - Op# 900"

Case "LMRP - Op# 1000"
operation = 60
oprtname = "LMRP - Op# 1000"
Case "LMRP - Op# 1100"
  operation = 61
  oprtname = "LMRP - Op# 1100"
Case "LMRP - Op# 1200"
  operation = 62
  oprtname = "LMRP - Op# 1200"
Case "LMRP - Op# 1400"
  operation = 63
  oprtname = "LMRP - Op# 1400"
Case "LMRP - Op# 1500"
  operation = 64
  oprtname = "LMRP - Op# 1500"
Case "LMRP - Op# 1800"
  operation = 65
  oprtname = "LMRP - Op# 1800"
Case "LMRP - Op# 1900"
  operation = 66
  oprtname = "LMRP - Op# 1900"
Case "LMRP - Op# 2000"
  operation = 67
  oprtname = "LMRP - Op# 2000"
Case "LMRP - Op# 2100"
  operation = 68
  oprtname = "LMRP - Op# 2100"
Case "LMRP - Op# 2200"
  operation = 769
  oprtname = "LMRP - Op# 2200"
Case "LMRP - Op# 2300"
  operation = 70
  oprtname = "LMRP - Op# 2300"
Case "LMRP - Op# 2400"
  operation = 71
  oprtname = "LMRP - Op# 2400"
Case "LMRP - Op# 2500"
  operation = 72
  oprtname = "LMRP - Op# 2500"
Case "LMRP - Op# 2600"
  operation = 73
  oprtname = "LMRP - Op# 2600"
Case "LMRP - Op# 2700"
  operation = 74
  oprtname = "LMRP - Op# 2700"
Case "LMRP - Op# 2800"
  operation = 75
  oprtname = "LMRP - Op# 2800"
Case "LMRP - Op# 2900"
operation = 76
oprtname = "LMRP - Op# 2900"
Case "LMRP - Op# 3000"
operation = 77
oprtname = "LMRP - Op# 3000"
Case "LMRP - Op# 3100"
operation = 78
oprtname = "LMRP - Op# 3100"
Case "LMRP - Op# 3200"
operation = 79
oprtname = "LMRP - Op# 3200"
Case "LMRP - Op# 3300"
operation = 80
oprtname = "LMRP - Op# 3300"
Case "LMRP - Op# 3400"
operation = 81
oprtname = "LMRP - Op# 3400"
Case "LMRP - Op# 3500/3600"
operation = 82
oprtname = "LMRP - Op# 3500/3600"
Case "LMRP - Op# 3700"
operation = 83
oprtname = "LMRP - Op# 3700"
Case "LMRP - Op# 3800/3900/4000/4100"
operation = 84
oprtname = "LMRP - Op# 3800/3900/4000/4100"
Case "LMRP - Op# 4200"
operation = 85
oprtname = "LMRP - Op# 4200"
Case "LMRP - Op# 4300"
operation = 86
oprtname = "LMRP - Op# 4300"
Case "LMRP - Op# 4400"
operation = 87
oprtname = "LMRP - Op# 4400"
Case "LMRP - Op# 4400b"
operation = 88
oprtname = "LMRP - Op# 4400b"
Case "LMRP - Op# 4400c"
operation = 89
oprtname = "LMRP - Op# 4400c"
Case "TTD - Op# 400"
operation = 90
oprtname = "TTD - Op# 400"
Case "TTD - Op# 600"
operation = 91
oprtname = "TTD - Op# 600"
Case "TTD - Op# 700"
    operation = 92
    oprtname = "TTD - Op# 700"
Case "TTD - Op# 800"
    operation = 93
    oprtname = "TTD - Op# 800"
Case "TTD - Op# 1200"
    operation = 94
    oprtname = "TTD - Op# 1200"
Case "TTD - Op# 1800"
    operation = 95
    oprtname = "TTD - Op# 1800"
Case "TTD - Op# 1400"
    operation = 96
    oprtname = "TTD - Op# 1400"
Case "TTD - Op# 1600"
    operation = 97
    oprtname = "TTD - Op# 1600"
Case "TTD - Op# 2000"
    operation = 98
    oprtname = "TTD - Op# 2000"
End Select

Unload delayUserForm
'OrderUserForm.Show
questionForm.Show
'Call addLabelnew(operation)

End Sub

Private Sub CommandButton2_Click()
Unload delayUserForm
End Sub

Private Sub UserForm_Initialize()

With delayListBox
    .AddItem "LWR STACK - Op# 200"
    .AddItem "LWR STACK - Op# 300"
    .AddItem "LWR STACK - Op# 400"
    .AddItem "LWR STACK - Op# 500"
    .AddItem "LWR STACK - Op# 600"
    .AddItem "LWR STACK - Op# 700"
    .AddItem "LWR STACK - Op# 800"
    .AddItem "LWR STACK - Op# 900"
End With

.AddItem "LMRP - Op# 200"
.AddItem "LMRP - Op# 400"
.AddItem "LMRP - Op# 500"
.AddItem "LMRP - Op# 600"
.AddItem "LMRP - Op# 700"
.AddItem "LMRP - Op# 800"
.AddItem "LMRP - Op# 900"
.AddItem "LMRP - Op# 1000"
.AddItem "LMRP - Op# 1100"
.AddItem "LMRP - Op# 1200"
.AddItem "LMRP - Op# 1400"
.AddItem "LMRP - Op# 1500"
.AddItem "LMRP - Op# 1800"
.AddItem "LMRP - Op# 1900"
.AddItem "LMRP - Op# 2000"
.AddItem "LMRP - Op# 2100"
.AddItem "LMRP - Op# 2200"
.AddItem "LMRP - Op# 2300"
.AddItem "LMRP - Op# 2400"
.AddItem "LMRP - Op# 2500"
.AddItem "LMRP - Op# 2600"
.AddItem "LMRP - Op# 2700"
.AddItem "LMRP - Op# 2800"
.AddItem "LMRP - Op# 2900"
.AddItem "LMRP - Op# 3000"
.AddItem "LMRP - Op# 3100"
.AddItem "LMRP - Op# 3200"
.AddItem "LMRP - Op# 3300"
.AddItem "LMRP - Op# 3400"
.AddItem "LMRP - Op# 3500/3600"
.AddItem "LMRP - Op# 3700"
.AddItem "LMRP - Op# 3800/3900/4000/4100"
.AddItem "LMRP - Op# 3700"
.AddItem "LMRP - Op# 4200"
.AddItem "LMRP - Op# 4300"
.AddItem "LMRP - Op# 4400"
.AddItem "LMRP - Op# 4400b"
.AddItem "LMRP - Op# 4400c"

.AddItem "TTD - Op# 400"
.AddItem "TTD - Op# 600"
.AddItem "TTD - Op# 700"
.AddItem "TTD - Op# 800"
.AddItem "TTD - Op# 1200"
.AddItem "TTD - Op# 1800"
.AddItem "TTD - Op# 1400"
.AddItem "TTD - Op# 1600"
.AddItem "TTD - Op# 2000"

End With
delayUserForm.delayListBox.Selected(0) = True

End Sub

ProjUserForm

Private Sub CommandButton1_Click()

Cells(6, 18).Value = ProjnameTextBox.Text
Cells(7, 18).Value = ProjIDTextBox.Text
Cells(8, 18).Value = PadListBox.Value
Unload ProjUserForm

End Sub

Private Sub CommandButton2_Click()
Unload ProjUserForm
End Sub

Private Sub UserForm_Initialize()

With PadListBox
 .AddItem "PAD 1"
 .AddItem "PAD 2"
 .AddItem "PAD 3"
 .AddItem "PAD 4"
 .AddItem "PAD 5"
 .AddItem "PAD 6"
 .AddItem "PAD 7"
End With
PadListBox.Selected(0) = True

End Sub

questionForm

Private Sub CommandButton1_Click()

If completion Then
delayoption = 1
Unload questionForm
AssyUserForm.Show

End Sub
End If
If start Then
delayoption = 0
Unload questionForm
Call addLabelnew(operation)
End If

End Sub

Private Sub UserForm_Initialize()

With completion
  .Caption = "Change completion time of " & oprtname
End With
With start
  .Caption = "Change start time of " & oprtname
End With

End Sub

ShiftUserform

Private Sub CommandButton1_Click()

Dim shift As Integer
Dim workdays As Integer
If UpperOption Then
  shift = 8
ElseIf MiddleOption Then
  shift = 10
ElseIf LowerOption Then
  shift = 12
End If
Cells(6, 52).Value = shift
If Option5hrs Then
  workdays = 5
ElseIf Option6hrs Then
  workdays = 6
ElseIf Option7hrs Then
  workdays = 7
End If
Cells(8, 51).Value = workdays
Unload ShiftUserform

End Sub
Private Sub CommandButton2_Click()
Unload ShiftUserform
End Sub

StartDateUserform

Private Sub UserForm_Initialize()
Dim dates As String

With monthListBox
  .AddItem "January"
  .AddItem "February"
  .AddItem "March"
  .AddItem "April"
  .AddItem "May"
  .AddItem "June"
  .AddItem "July"
  .AddItem "August"
  .AddItem "September"
  .AddItem "October"
  .AddItem "November"
  .AddItem "December"
End With

StartDateUserform.monthListBox.Selected(0) = True

With DayListBox
  .AddItem "01"
  .AddItem "02"
  .AddItem "03"
  .AddItem "04"
  .AddItem "05"
  .AddItem "06"
  .AddItem "07"
  .AddItem "08"
  .AddItem "09"
  .AddItem "10"
  .AddItem "11"
  .AddItem "12"
  .AddItem "13"
  .AddItem "14"
  .AddItem "15"
  .AddItem "16"

With YearListBox

    .AddItem "2010"
    .AddItem "2011"
    .AddItem "2012"
    .AddItem "2013"
    .AddItem "2014"
    .AddItem "2015"
    .AddItem "2016"
    .AddItem "2017"
    .AddItem "2018"
    .AddItem "2019"
    .AddItem "2020"
    .AddItem "2021"
    .AddItem "2022"
    .AddItem "2023"
    .AddItem "2024"
    .AddItem "2025"
    .AddItem "2026"
    .AddItem "2027"
    .AddItem "2028"
    .AddItem "2029"
    .AddItem "2030"
    .AddItem "2031"
End With

StartDateUserform.YearListBox.Selected(0) = True
'Select the first list item
monthListBox.ListIndex = 0
DayListBox.ListIndex = 0
YearListBox.ListIndex = 0

End Sub

Private Sub CommandButton1_Click()

' CLEARS THE delay_report sheet
Sheets("Sequence&Labor").Cells(7, 53).Value = 1 '***used in the MODULE1 to store critical paths in the critical_path sheet
'pathcounter = 1 'used in the MODULE1 to store critical paths in the critical_path sheet
Sheets("delay_report").Cells.Delete 'used to clear all the contents in the critical_paths sheet

' CLEARS THE criticals_path sheet
Sheets("Sequence&Labor").Cells(6, 53).Value = 1 '***used in the MODULE1 to store critical paths in the critical_path sheet
'pathcounter = 1 'used in the MODULE1 to store critical paths in the critical_path sheet
Sheets("critical_paths").Cells.Delete 'used to clear all the contents in the critical_paths sheet

' CLEARS THE yellow color used to indicate the critical path
Range("B5:M104").Select  'clearing yellow color used to indicate the critical path
With Selection.Interior
  .Pattern = xlNone
  .TintAndShade = 0
  .PatternTintAndShade = 0
End With

' ENTERS THE START DATE IN A SPECIFIC CELL
Cells(6, 51).Value = DayListBox.Value + 1 & monthListBox.Value &
YearListBox.Value '***daylistbox.value needs to be added by 1 to get right value

' CLEARS ALL THE DATES FROM THE PART SHEET
Dim c_rowsize As Integer
Dim c_opt As Integer
Dim c_list As Integer
Dim c_assy As Integer

For c_opt = 1 To 196 Step 2
  c_rowsize =
  (Application.WorksheetFunction.CountA(Worksheets("part").Columns(c_opt))) - 7
For c_list = 5 To c_rowsize + 4
  Sheets("part").Cells(c_list, c_opt + 1).Value = "N/A"
Next c_list
  c_assy = 0
  Do
  c_assy = c_assy + 1
  Loop Until (Sheets("part").Cells(c_assy, c_opt).Value) = "Assy. delay" 'counts the row which has assy delay date in "part" sheet
  Sheets("part").Cells(c_assy, c_opt + 1).Value = "N/A"
Next c_opt
Unload StartDateUserform

' CLEARS CONTENTS FROM THE CRITICAL PATH SHEET
Sheets("critical_paths").Cells.ClearContents
' POPULATES THE DROP DOWN LIST WITH NO AS DEFAULT
Range("M5:M55").Value = Cells(13, 50).Value
Range("M57:M94").Value = Cells(13, 50).Value
Range("M96:M104").Value = Cells(13, 50).Value

End Sub

Private Sub CommandButton2_Click()
Unload StartDateUserform
End Sub

UserForm1

Private Sub CommandButton1_Click()
'If (Weekday(Sheets("part").Cells(UserForm.ActiveControl.Name + 4, (2 * operation)).Value, 1) = 1) Then
'MsgBox "entered date is a sunday please enter new date"
'Else
Sheets("part").Cells(UserForm.ActiveControl.Name + 4, (2 * operation)).Value = DayListBox2.Value + 1 & monthListBox2.Value & YearListBox2.Value
'daylistbox.value needs to be added by 1 to get right value
'End If
Unload UserForm1
'Call delay_calc

End Sub

Private Sub CommandButton2_Click()
Unload UserForm1
End Sub

Private Sub UserForm_Initialize()
Dim dates As String
With monthListBox2
    .AddItem "January"
    .AddItem "February"
    .AddItem "March"
    .AddItem "April"
    .AddItem "May"
    .AddItem "June"
    .AddItem "July"
    .AddItem "August"
    .AddItem "September"
    .AddItem "October"
    .AddItem "November"
    .AddItem "December"
End With
UserForm1.monthListBox2.Selected(0) = True

With DayListBox2
    .AddItem "01"
    .AddItem "02"
    .AddItem "03"
    .AddItem "04"
    .AddItem "05"
    .AddItem "06"
    .AddItem "07"
    .AddItem "08"
    .AddItem "09"
    .AddItem "10"
    .AddItem "11"
    .AddItem "12"
    .AddItem "13"
.AddItem "14"
.AddItem "15"
.AddItem "16"
.AddItem "17"
.AddItem "18"
.AddItem "19"
.AddItem "20"
.AddItem "21"
.AddItem "22"
.AddItem "23"
.AddItem "24"
.AddItem "25"
.AddItem "26"
.AddItem "27"
.AddItem "28"
.AddItem "29"
.AddItem "30"
.AddItem "31"
End With

UserForm1.DayListBox2.Selected(0) = True

With YearListBox2

 .AddItem "2010"
 .AddItem "2011"
 .AddItem "2012"
 .AddItem "2013"
 .AddItem "2014"
 .AddItem "2015"
 .AddItem "2016"
 .AddItem "2017"
 .AddItem "2018"
 .AddItem "2019"
 .AddItem "2020"
 .AddItem "2021"
 .AddItem "2022"
 .AddItem "2023"
 .AddItem "2024"
 .AddItem "2025"
 .AddItem "2026"
 .AddItem "2027"
 .AddItem "2028"
 .AddItem "2029"
 .AddItem "2030"
 .AddItem "2031"
End With

UserForm1.YearListBox2.Selected(1) = True
'Select the first list item
monthListBox2.ListIndex = 0
DayListBox2.ListIndex = 0
YearListBox2.ListIndex = 0

End Sub
Appendix B.2 - PAD_LAYOUT Excel VBA code

Module 1

Sub CopySheetToOtherWbk()

Dim CopyFromBook As Workbook
Dim CopyToWbk As Workbook
Dim ShToCopy As Worksheet
Dim path As String
Dim fullpath As String

path = Cells(8, 36).Value & "\" & Cells(10, 36).Value & ".xlsm"
MsgBox path

Workbooks.Open path

Set CopyFromBook = Workbooks("CPM_new")
Set ShToCopy = CopyFromBook.Worksheets("delay_report")
Set CopyToWbk = Workbooks("PAD_LAYOUT")
ShToCopy.Copy After:=CopyToWbk.Sheets(CopyToWbk.Sheets.Count)

End Sub

Module 2

Sub PAD_1()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Application.ScreenUpdating = False
openworksheet ("PAD1.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD1").Activate
Application.Run ("PAD1.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True

End Sub
Sub PAD_2()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Application.ScreenUpdating = False
openworksheet ("PAD2.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD2").Activate
Application.Run ("PAD2.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True

End Sub

Sub PAD_3()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
Application.ScreenUpdating = False
openworksheet ("PAD3.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD3").Activate
Application.Run ("PAD3.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True

End Sub

Sub PAD_4()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True Application.ScreenUpdating = False
openworksheet ("PAD4.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD4").Activate
Application.Run ("PAD4.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If

End Sub
Application.ScreenUpdating = True

End Sub

Sub PAD_5()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True
Application.ScreenUpdating = False
openworksheet ("PAD5.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD5").Activate
Application.Run ("PAD5.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True

End Sub

Sub PAD_6()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True
Application.ScreenUpdating = False
openworksheet ("PAD6.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD6").Activate
Application.Run ("PAD6.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True

End Sub

Sub PAD_7()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True
Application.ScreenUpdating = False
openworksheet ("PAD7.xlsm") ' opens the delay_report from the corresponding file
If Check <> 0 Then
Workbooks("PAD7").Activate
Application.Run ("PAD7.xlsm!delay_report")
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate
End If
Application.ScreenUpdating = True
Module 3

Function BrowseForFolder(Optional OpenAt As Variant) As Variant

'Function purpose: To Browser for a user selected folder.
'If the "OpenAt" path is provided, open the browser at that directory
'NOTE: If invalid, it will open at the Desktop level

Dim ShellApp As Object
'Create a file browser window at the default folder
Set ShellApp = CreateObject("Shell.Application"). _
  BrowseForFolder(0, "Please choose a folder", 0, OpenAt)
'Set the folder to that selected. (On error in case cancelled)
On Error Resume Next
  BrowseForFolder = ShellApp.self.path
On Error GoTo 0
'Destroy the Shell Application
Set ShellApp = Nothing
'Check for invalid or non-entries and send to the Invalid error handler if found
'Valid selections can begin L: (where L is a letter) or \ (as in \servername\sharename. All others are invalid
Select Case Mid(BrowseForFolder, 2, 1)
  Case Is = ":"
    If Left(BrowseForFolder, 1) = ":" Then GoTo Invalid
  Case Is = "\\"
    If Not Left(BrowseForFolder, 1) = "\\" Then GoTo Invalid
  Case Else
    GoTo Invalid
End Select
Exit Function
Invalid:
  BrowseForFolder = False

End Function

Sub Choosefolder()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True

Dim FilePaths As String
Dim result As String
FilePaths = BrowseForFolder
Cells(8, 36).Value = FilePaths
End Sub

Module 4

Global FileName As String
Global Check As Integer

Public Function GetValue(path, file, sheet, ref)
' Retrieves a value from a closed workbook
Dim arg As String
' Make sure the file exists
If Right(path, 1) <> "\" Then path = path & "\"
If Dir(path & file) = "" Then
   GetValue = "File Not Found"
   Exit Function
End If
' Create the argument
arg = "" & path & "]" & file & "]" & sheet & "!" & _
   Range(ref).Range("A1").Address(, , xlR1C1)
' Execute an XLM macro
GetValue = ExecuteExcel4Macro(arg)

End Function

Public Function openworksheet(file)
Dim path As String
Check = 1
Call CloseAllSheetsExActive
path = Cells(8, 36).Value & "\" & file
If Dir(path) = "" Then
   MsgBox "File Not Found"
   Check = 0
   Exit Function
End If
Workbooks.Open path
Sheets("delay_report").Activate
'Workbooks("PAD_LAYOUT").Activate

End Function
Module 5

Sub Update()

Worksheets("Layout").Protect Password:="novms", UserInterfaceOnly:=True 'Protects the work sheet
UpdateUserForm.Show

End Sub

Module 6

Sub CloseAllSheetsExActive() ' closes all the inactive worksheets

Dim WBs As Workbook
For Each WBs In Application.Workbooks
If Not WBs.Name = ThisWorkbook.Name Then WBs.Close
Next WBs

End Sub
Appendix C - Sample T – Test for data Validation

One-Sample T: Percentage Deviation

<table>
<thead>
<tr>
<th>Variable</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>SE Mean</th>
<th>95% CI</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>7</td>
<td>7.63</td>
<td>5.54</td>
<td>2.09</td>
<td>(2.51, 12.75)</td>
</tr>
</tbody>
</table>

Probability Plot of Percentage Dev.
Normal - 95% CI

Mean 7.631
StDev 5.536
N 7
AD 0.417
P-Value 0.232